CORPS OF ENGINEERS, U. S. ARMY

OUTLET WORKS STILLING BASIN FOR TEXARKANA DAM

SULPHUR RIVER, TEXAS

HYDRAULIC MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-346

WATERWAYS EXPERIMENT STATION

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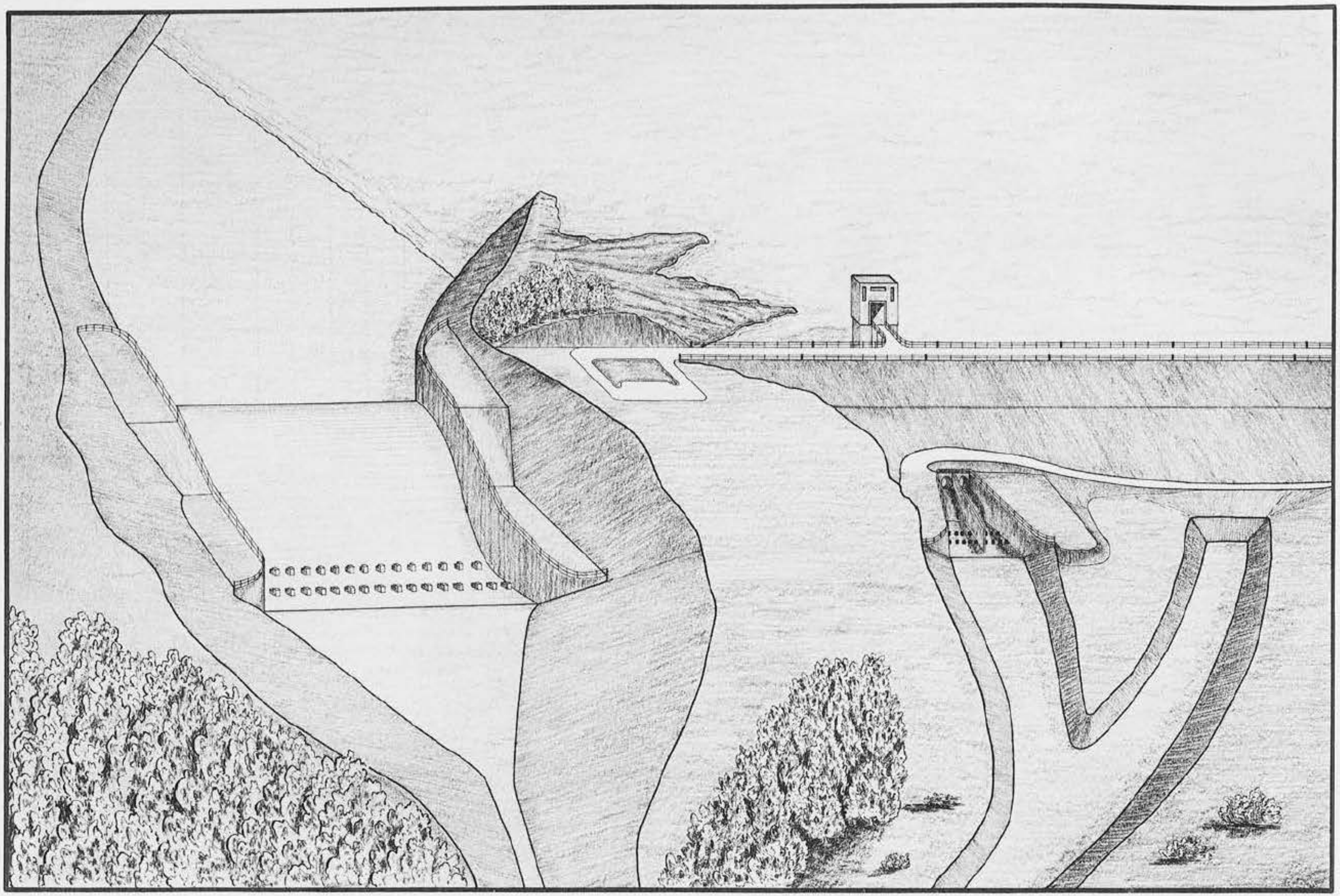

FRONTISPIECE. Texarkana Dam Control Structures

PREFACE

Model investigations of the outlet works stilling basin for Texarkana Dam were authorized by the Chief of Engineers in the third indorsement to a letter to the Division Engineer, Lower Mississippi Valley Division, dated 10 May 1949. The model studies were conducted during the period May 1949-June 1950 in the Hydraulics Division of the Waterways Experiment Station by Messrs. T. J. Buntin, John N. Strange, and C. M. Wright, under the general supervision of Messrs. F. R. Brown and T. E. Murphy.

Messrs. E. J. Williams, J. E. Sanders, C. L. Sumrall, Jr., and F. B. Toffaleti, engineers of the Lower Mississippi Valley Division, visited the Experiment Station at frequent intervals during the course of the study to discuss testing procedures and to correlate test results with design work being accomplished concurrently.

CONTENTS

SUMMARY

The outlet works stilling basin for Texarkana Dam was studied on a 1:25-scale model to insure adequacy of the basin in reducing the velocity of flow issuing from the twin conduits.

Initial tests indicated the necessity for revision of various stilling basin elements. Energy of flow from the conduits operating singly, or in combination, was not diminished as the flow passed through the stilling basin. Flow concentrated in areas adjacent to the splitter wall and had upstream direction adjacent to the outside basin walls.

The desired performance of the stilling basin was secured by use of warped transition sections downstream from the conduit exit portals, elimination of the stepped apron, and reduction of 3 ft in the height of the splitter wall. The elevation of the stilling basin and height of end sill were not changed.

OUTLET WORKS STILLING BASIN FOR TEXARKANA DAM

SULPHUR RIVER, TEXAS

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. Texarkana Dam is an earth-fill dam under construction on the Sulphur River approximately 9 miles southwest of Texarkana, Texas (fig. 1). It will be approximately 100 ft high and 18,500 ft long. The reservoir created by the dam will have an area of 119,700 acres at spillway crest elevation of 259.5* and a total storage capacity of 2,654,300 acre-ft. The reservoir will extend up the Sulphur River approximately 40 miles. The reservoir will be 20,300 acres in area and will store 145,300 acre-ft at the conservation pool elevation of 220.

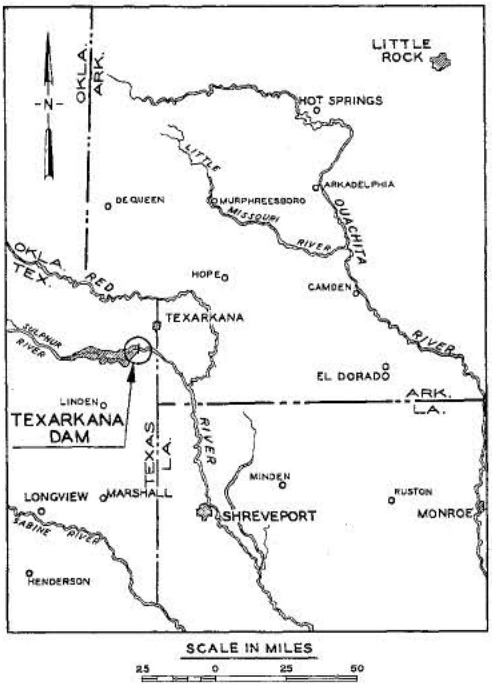

Fig. 1. Vicinity map

2. Normal flow regulation will be accomplished by means of four slide gates located within the intake structure of the outlet works. Flow from the intake structure will pass through two circular conduits

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* All elevations are in feet above mean sea level.

20 ft in diameter and approximately 480 ft in length, discharging into a hydraulic-jump type stilling basin. Design capacity of the outlet works is 28,000 cfs. Details of the stilling basin as originally designed and as revised are shown on plates 1 and 9, respectively.

3. Flows exceeding the storage capacity of the reservoir will pass over an uncontrolled chute-type spillway located in the right abutment of the dam (see frontispiece). The spillway, with crest at elev 259.5, is designed to pass a maximum discharge of 66,800 cfs under a head of 19.2 ft. High velocity flow will be reduced at the toe of the spillway by means of a hydraulic-jump type stilling basin.

Purpose of Model Analysis

4. Previous experience has indicated that satisfactory stilling basin performance is difficult to procure where symmetry of basin dimensions is not maintained about the center line of each conduit. The general purpose of the model studies, therefore, was to examine the performance of the stilling basin of the outlet structures as originally designed and to make such revisions as appeared necessary to effect economies or improve flow conditions.

PART II: THE MODEL

Description

5. The model of Texarkana Dam outlet works was constructed to an undistorted scale ratio of 1:25 (photograph 3) and reproduced approximately 400 ft of the conduits, the complete stilling basin and about 300 ft of the exit channel. The intake structure and upstream transition section were not reproduced.

6. The stilling basin area was constructed of concrete and wood to facilitate alterations. The twin conduits were fabricated of sheet metal. Two metal gates with air vents were located at the upstream end of the model conduits at the junction with the headbay of the model for regulation of flow and simulation of prototype conditions.

7. The water used in the operation of the model was supplied by a circulating system, the measurement of discharge being accomplished by use of a venturi meter installed in the inflow line. Flow from the supply line was discharged into the headbay where it was stilled by baffles prior to its entrance into the conduits. The tailwater elevation in the exit area was controlled by means of an adjustable tailgate. After passing over the control tailgate the water flowed through a return line back to the sump from which it was originally pumped.

8. Steel rails set to grade along each side of the model provided a reference plane for use of all measuring devices. Average water-surface elevation was measured by means of a portable sounding rod placed on an angle-beam supported by the rails. Velocities were measured by means of a pitot tube arranged in a bracket to enable

measurements to be made for any direction of flow. Flow conditions were recorded by means of photographs. The bed of the exit channel was molded in sand for scour tests, and was capped with cement mortar for velocity measurements. All scour tests were of one hour duration, model time.

Scale Ratios

9. The accepted equations of hydraulic similitude, based on the Froudian relationships, were used to express the mathematical relationships between the dimensions and hydraulic quantities of the model and the prototype. General relationships for the transference of model data to prototype equivalents, or vice versa, are presented in the following table:

Dimension	Ratio	Scale Relationship
Length	L_r	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3,125
Roughness	$n_r = L_r^{1/6}$	1:1.710

PART III: TESTS AND RESULTS

10. It was necessary in all tests to adjust the discharge in accordance with the computed pool-discharge relations furnished by representatives of the Lower Mississippi Valley Division, since the intake structure was not reproduced in the model. Discharge conditions for which data were desired are tabulated below:

Discharge, cfs	Pool Elevation	Tailwater Elevation
5,000	259.5	203.95
10,000	259.5	210.0
10,000	242.5	210.0
10,000	222.2	210.0
10,000	259.5	212.3
14,000	259.5	212.3
15,000	259.5	212.45
18,000	259.5	213.1
28,000	259.5	214.7

Discharges of 10,000 and 18,000 cfs with their respective pool and tailwater conditions were considered most important for investigation. Discharges in excess of 18,000 cfs will be infrequent, although the outlet structures were designed for a maximum capacity of 28,000 cfs. A discharge of 14,000 cfs with only one conduit in operation was most critical for investigation of effect of splitter-wall elevation.

11. Test data are not presented for many of the alterations tried in the model, because if an alteration obviously made no improvement in flow conditions it was changed immediately without further investigation.

Original Design

12. Tests of the original design stilling basin (plate 1) indicated unsatisfactory flow conditions for all discharges. Although flow

was symmetrical about the center line of the stilling basin, strong downstream currents existed along the splitter wall whereas currents along the spray walls were upstream in direction (photographs 1 and 2). Conditions existing within each half of the stilling basin are also shown diagrammatically in fig. 2. The upstream currents along the spray walls

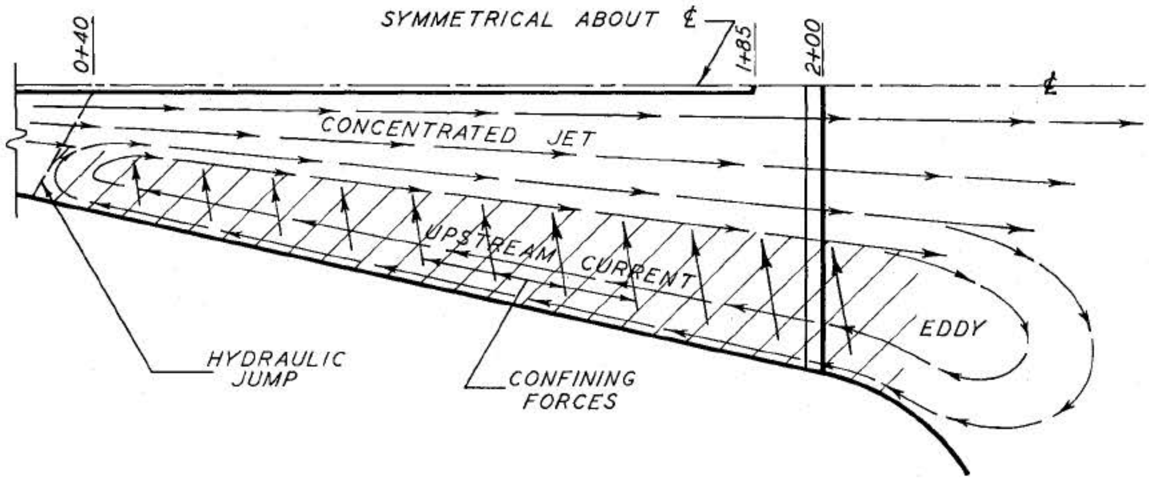


Fig. 2. Flow in stilling basin of original design

actually helped confine the high velocity jets issuing from the conduits against the splitter wall. Thus little or no reduction in velocity was effected as flow passed through the stilling basin. The shaded portion of the basin shown in the figure contributed nothing toward improving basin performance. The stepped portion of the apron appeared to have little or no effect on flow distribution within the stilling basin.

13. Prior to the start of each scour test the bed of the exit channel was molded to elev 180. Scour caused by the flow conditions depicted in photographs 1 and 2 are shown on photographs 3 and 4. These data indicate that the upstream flow along the spray walls was of sufficient magnitude to transport bed material from the exit area into the

stilling basin. The lack of appreciable scour downstream from the end sill is an indication that the high velocities were confined to surface flow.

14. Velocities measured over the cross section of the basin at the end sill indicate the extent and magnitude of the currents in the stilling basin for various discharges (plates 2-3). Downstream flow was confined to the center third of the stilling basin and varied in velocity from about 5 ft per sec at the end sill to 13 ft per sec at the water surface for a discharge of 18,000 cfs.

Alterations to Original Design

Baffle piers

15. Initial efforts to improve stilling basin performance involved alterations to the height, shape, and location of baffle piers. Baffle piers 4 and 8 ft in height and either stepped or vertical were investigated. The baffle piers, for the most part, were located in rows perpendicular to the splitter wall; however, one test was conducted wherein the baffle piers were slanted diagonally across the halves of the stilling basin, i.e., the baffle pier adjacent to the splitter wall was farther upstream than the baffle pier in the same row adjacent to the spray wall. Elimination of all baffle piers to study the absolute effect of the piers indicated that they were of some use in reducing the velocity of flow passing through the stilling basin. Comparison of the scour data (photograph 5) obtained after removal of the baffle piers with the scour data (photograph 3) obtained with the basin of original design indicates an increase in scour resulting from elimination of the baffle piers. Tests

of other alterations to the baffle piers indicated no improvement in basin performance over that obtained with the basin of original design. The high velocity flow issuing from the conduits pushed the tailwater farther downstream as the baffle piers were reduced in height or were moved downstream. Therefore it was decided to retain the original design of baffle piers, although flow was still confined to the middle third of the stilling basin.

Horizontal apron and end sill elevation

16. The horizontal apron and end sill were raised 5 ft to elevation 180 and 185, respectively, in an effort to improve flow distribution in the stilling basin. The effect of this alteration on basin performance was negligible, although velocities over the end sill were increased (plate 4). However, the magnitude of velocities over the end sill was less than that considered likely to cause erosion of the exit area. A 10-ft increase in the height of the end sill (top elevation 190) increased velocities (plate 4) and was considered undesirable. Therefore, an elevation of 180 was tentatively adopted for the horizontal apron in conjunction with a 5-ft-high end sill. Flow conditions were still about the same as those observed in the stilling basin of original design. The stilling basin was later returned to its original elevation to maintain the end sill at the same elevation as the exit channel downstream.

Sloped apron

17. Alterations to the angle of the steps forming the sloping portion of the basin floor failed to improve flow conditions. Velocities at the end sill, with the angle of flare of the steps with respect to the spray walls increased from 90 to 120 degrees (fig. 3), are shown on plate 5.

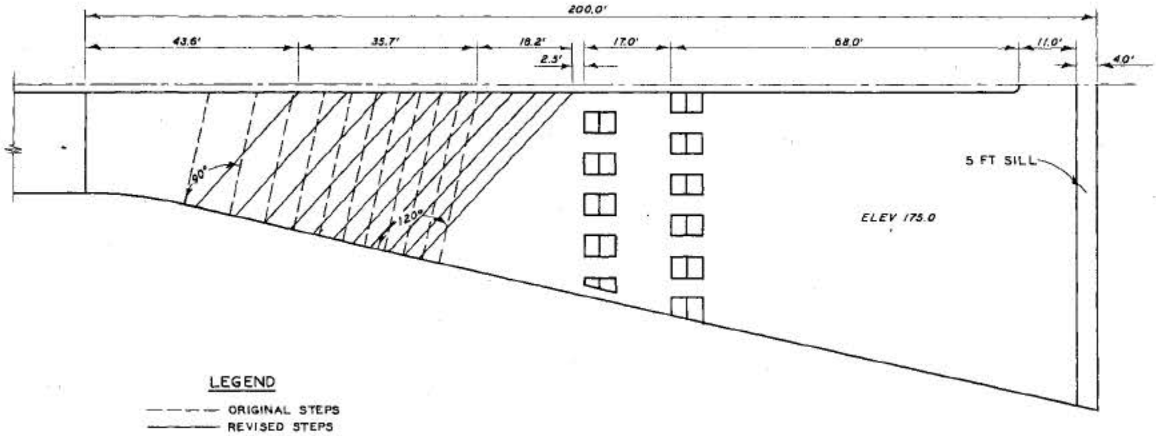


Fig. 3. Stilling basin with increased angle of flare of steps

Elimination of the steps entirely by molding a smooth curve to the equation of $X^2 = -270Y$ (fig. 4) had no effect on flow conditions. Thus, elimination of the steps from the stilling basin design appeared warranted. Although flow conditions were not affected by such revision, some economies in construction could be made.

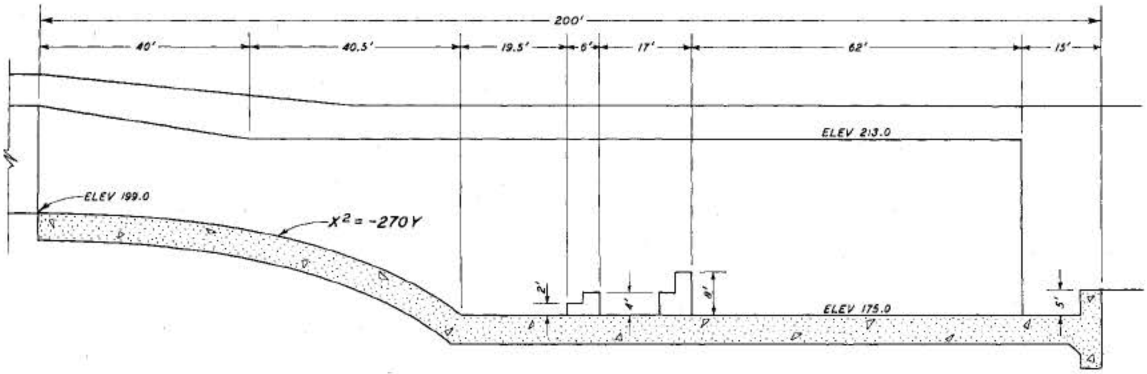


Fig. 4. Stilling basin with steps replaced by smooth curve

Stilling basin width

18. Efforts were directed toward elimination of the eddies adjacent to the spray walls by decreasing the width of the basin, inasmuch as neither alterations to the baffle piers nor to the basin floor effected

the desired improvement in flow conditions. Accordingly, the width of the stilling basin at the end sill was decreased from 127 to 82.5 ft. The resulting flow conditions (photograph 6) approached those desired. Eddy action adjacent to the spray walls was almost eliminated and better flow distribution within the basin resulted. Although velocities over the end sill were increased only slightly for a discharge of 10,000 cfs, velocities for a discharge of 18,000 cfs were considered excessive (plate 6). Therefore efforts to secure the desired flow distribution by reducing the width of the stilling basin were abandoned.

Deflector blocks at conduit exit portal

19. Efforts were made to direct the jets issuing from the conduits away from the splitter wall, since alteration of the stilling basin proper did not accomplish the desired results. The four types of deflector blocks investigated are shown in fig. 5. Use of the deflector blocks accomplished the desired flow distribution and stilling basin performance, and appeared to give the desired results (see plate 7). However, it was realized that the blocks would be subject to damage by debris and that a similar device to deflect the high velocity jet should be devised.

Revision of exit portal

20. Efforts to secure uniform flow distribution in the stilling basin included constriction of the conduit exit portal and use of a humped floor starting within the portal and extending into the stilling basin. None of these efforts was successful. Design engineers of the Lower Mississippi Valley Division were of the opinion that diversion of the high velocity jets should be accomplished within the confines of the stilling basin rather than within the conduit proper.

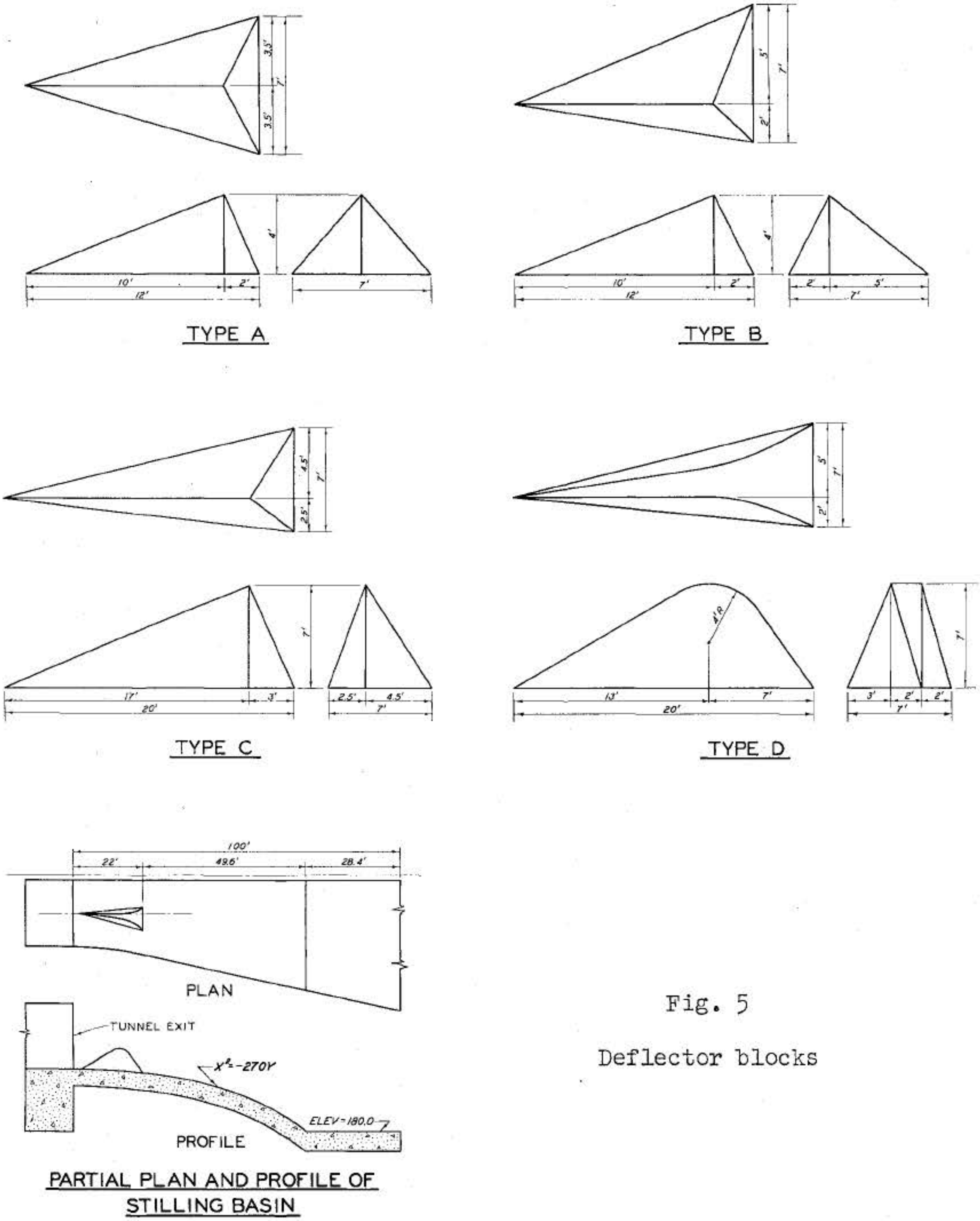


Fig. 5

Deflector blocks

Transitions at conduit exit portals

21. The length of the stilling basin was increased 50 ft at the conduit exit portals to provide additional length for deflection of the

high velocity jets. This increase in length of stilling basin was accomplished by shortening the conduits 50 ft. The stilling basin apron and end sill also were lowered to their original elevations of 175 and 180, respectively, at the request of engineers of the Lower Mississippi Valley Division. This was done to maintain the end sill at the same elevation as the exit channel downstream. The use of broad-crested weirs 5 to 7.5 ft in height and located about 50 ft downstream from the conduit exit portals was first investigated. Resulting flow conditions were considered unsatisfactory (photograph 7). Impact of flow on the weirs was excessive and the discharge capacity of the conduits was reduced. Wedge-shaped fillets of varying slopes adjacent to the splitter wall (fig. 6) were next

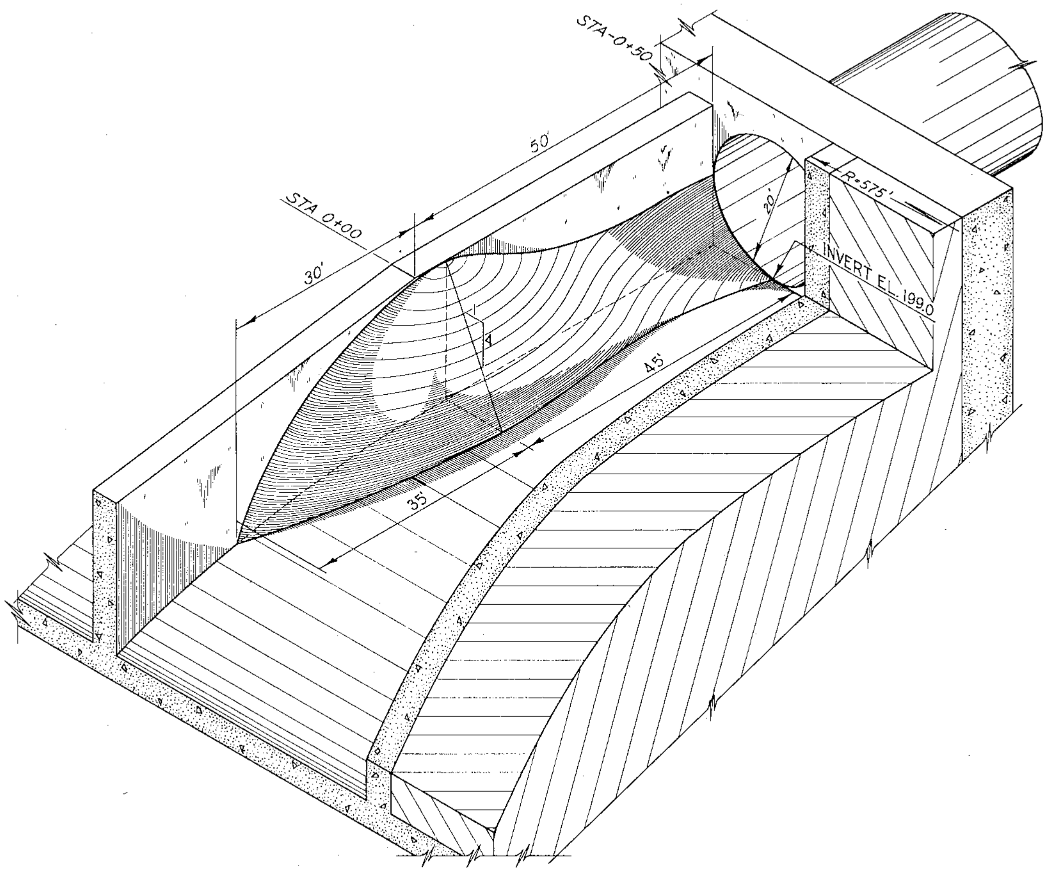
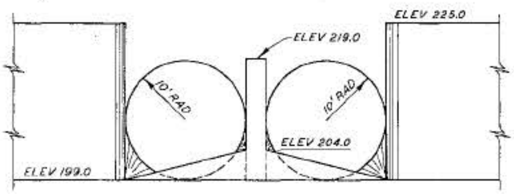
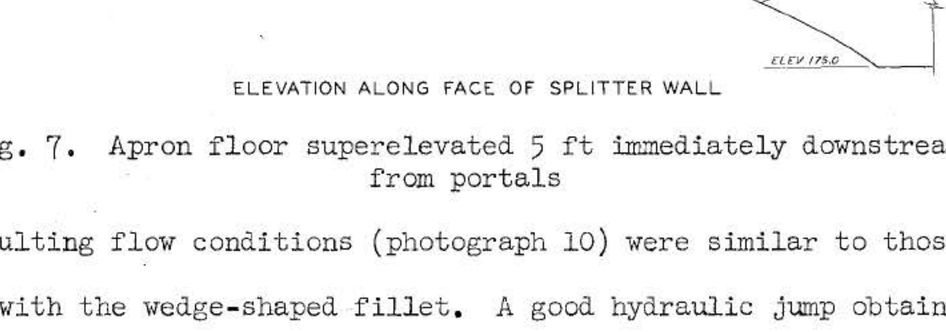


Fig. 6. Wedge-shaped fillets adjacent to splitter wall in stilling basin

investigated. Use of these fillets resulted in a marked improvement in flow conditions (photograph 8). A good hydraulic jump obtained and flow appeared evenly distributed across the stilling basin (plate 8). Erosion test data for flows of 10,000 and 18,000 cfs are presented in photograph 9. A third scheme was investigated, despite the fact that the desired flow conditions had been obtained, which involved a 5-ft superelevation of the apron floor immediately downstream from the exit portal (fig. 7). The radius of curvature of the spray walls in the immediate vicinity of the conduit exit portals also was increased from 100 to 575 ft.



SECTION 50' DOWNSTREAM OF TUNNEL EXIT



ELEVATION ALONG FACE OF SPLITTER WALL

Fig. 7. Apron floor superelevated 5 ft immediately downstream from portals

The resulting flow conditions (photograph 10) were similar to those observed with the wedge-shaped fillet. A good hydraulic jump obtained and flow appeared uniformly distributed. Since the superelevated transition results in a continuously submerged deflecting surface, it is believed superior to the wedge-shaped fillet for installation in the prototype

structure. Attempts to reduce the over-all length of the stilling basin from 250 to 200 ft were unsuccessful.

Splitter wall

22. Tests were made of various alterations to the splitter wall in an effort to effect economies in its construction. One test also was conducted with the splitter wall eliminated entirely. Elimination of the splitter wall destroyed all evidence of jump action and a large amount of scour in the exit area (photograph 11) resulted. Consequently, the splitter wall was considered an important part of the stilling basin. Alterations to the wall were investigated involving variation of the top elevation of the downstream portion of the wall from 213 to 198, and variation of the length of the wall. Tests of these alterations, with both conduits in operation, indicated the possibility of reducing the top elevation to 198 and shortening it to the second row of baffle piers. However, representatives of the Lower Mississippi Valley Division requested that the wall be designed to provide good stilling basin performance for a discharge of 14,000 cfs through one conduit. It was decided, on the basis of general hydraulic behavior of flow within the stilling basin and the maximum depth of scour noted in the exit area, that the lower end of the splitter wall should be at elevation 210. It also was determined from these data that the shortest length possible was 200 ft; thus, the wall was terminated 50 ft upstream from the end sill.

Recommended Design

23. The stilling basin design encompassing all of the most satisfactory elements derived from studies of the alterations previously

described is shown in photograph 12 and plate 9. Comparison of the physical features of the recommended design of stilling basin with those of the original design (plate 1) indicates the following:

a. The over-all length of stilling basin was increased 50 ft by reducing the length of the conduits.

b. A warped transition with a 5-ft superelevation of the apron floor at the conduit exit portals was used to secure the desired flow distribution.

c. The radius of the curved spray walls near the exit portals was increased from 100 to 575 ft.

d. The stepped portion of the apron was replaced with a smooth trajectory curve.

e. The downstream portion of the splitter wall was reduced 35 ft in length and the top lowered from elev 213 to 210.

24. Flow conditions within the stilling basin of recommended design were excellent for both twin- and single-conduit operation (photographs 12-14). Water-surface profiles showing the location of the hydraulic jump in each half of the stilling basin for the most important discharges are shown on plate 10. Results of erosion tests for the same discharges are shown in photographs 15 and 16. Comparison of these scour data with those obtained downstream from the stilling basin of original design (photographs 3 and 4) indicates considerable improvement. Velocity data measured over the cross section of the channel at the end sill are shown on plates 11 and 12. These data indicate uniform flow conditions across the channel. The maximum velocity recorded over the end sill for both conduits in operation was less than 4 ft per sec for all discharges. For conditions of one conduit operating (plate 11) the maximum velocity over the end sill was 7.6 ft per sec for a discharge of 14,000 cfs. The tailwater elevation could be lowered 15 ft for

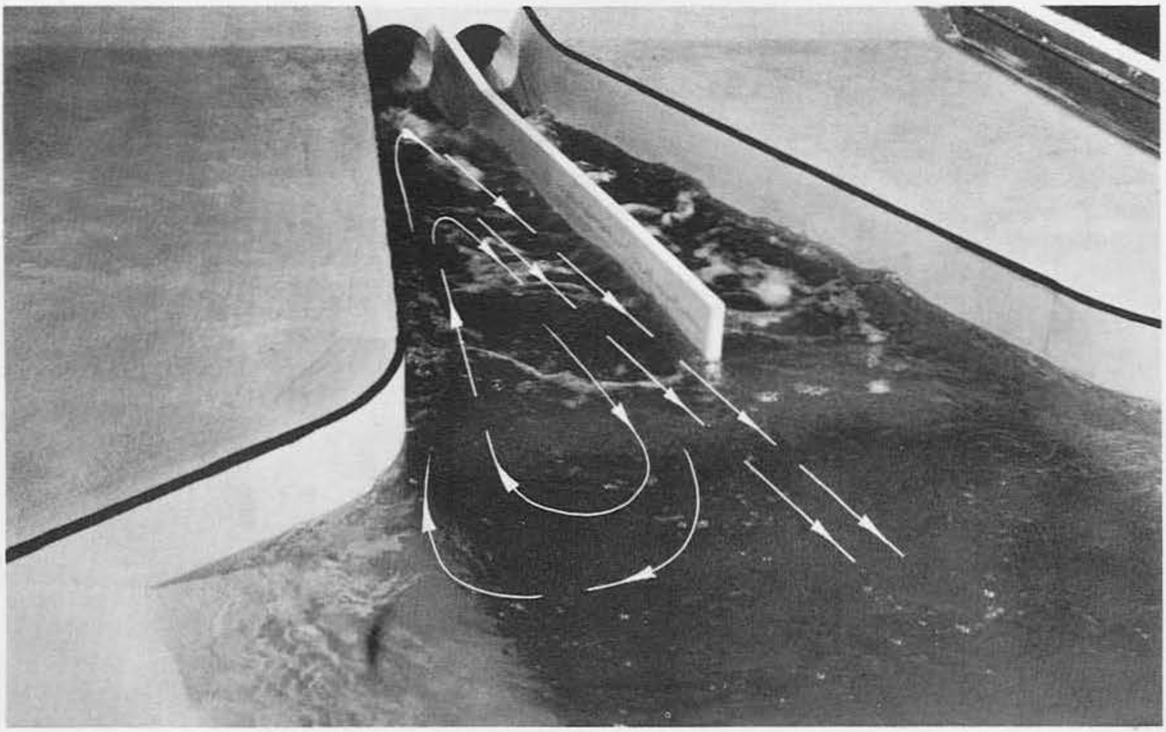
discharges of 10,000 and 18,000 cfs before spray action occurred (plate 13); at the maximum discharge of 28,000 cfs the tailwater could be lowered 10 ft before spray occurred. Variation in tailwater revealed that minimum end-sill velocities occurred at normal tailwater depth for a discharge of 10,000 cfs (plate 14). Minimum velocity occurred at a tailwater depth about 6 ft below normal for a discharge of 18,000 cfs.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

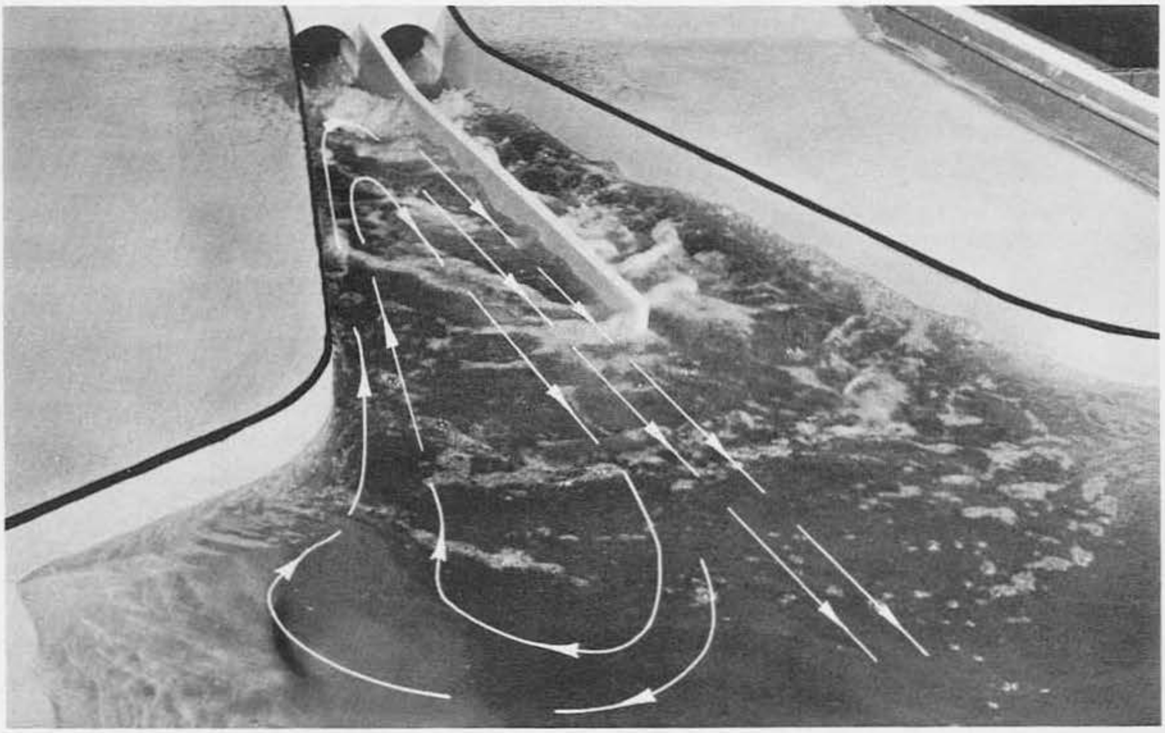
25. Model investigations permitted the development of a satisfactory design for all conditions of discharge and conduit operation. The most important aspect of the problem of securing good flow distribution in each half of the stilling basin was the development of a transition at the conduit exit portals. This transition involved the superelevation of the floor 5 ft to divert flow away from the splitter wall. It was necessary to increase the over-all length of the stilling basin 50 ft, inasmuch as it was desired to place the transition entirely outside the conduits rather than make it a part of the exit portal. The increase in length of the stilling basin was accomplished by shortening the conduits. Details of the stilling basin design recommended for construction in the prototype are shown on plate 9.

26. Flow conditions with the recommended stilling basin design were excellent for all conditions of discharge and conduit operation. Also a considerable reduction in tailwater, below that computed, could occur without decreasing the effectiveness of the stilling basin.

PHOTOGRAPHS

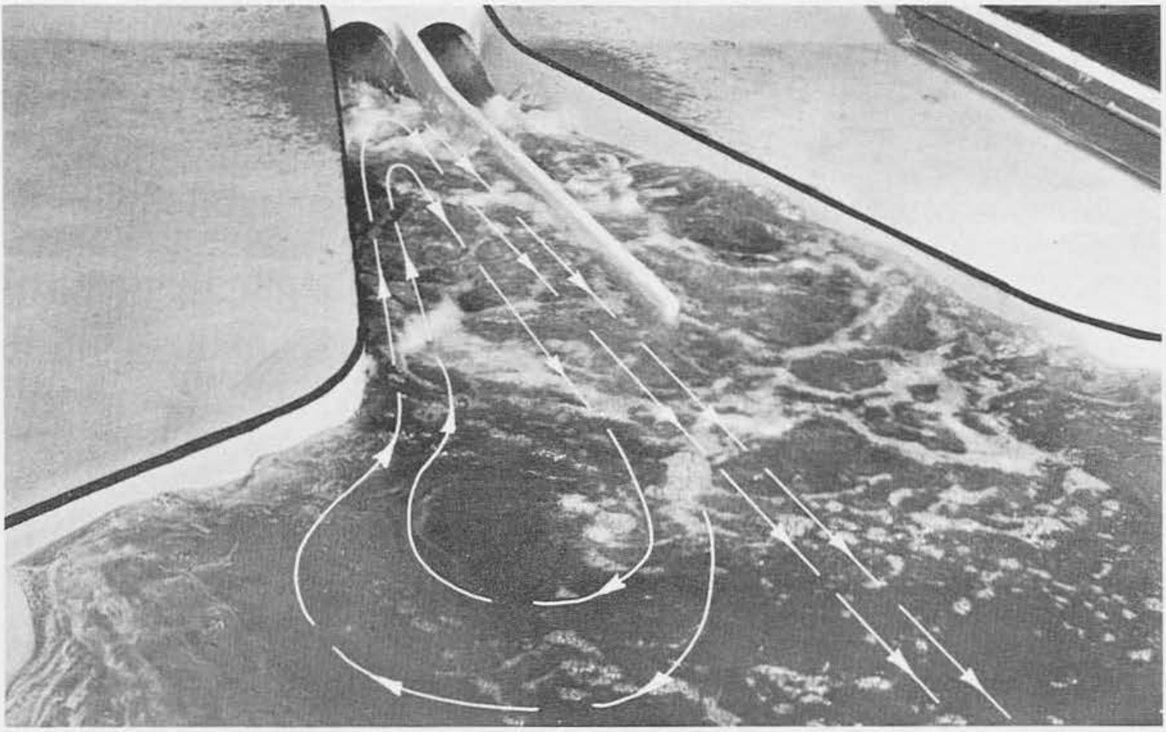


Discharge, 5,000 cfs; pool elev, 259.50; tailwater elev, 203.95

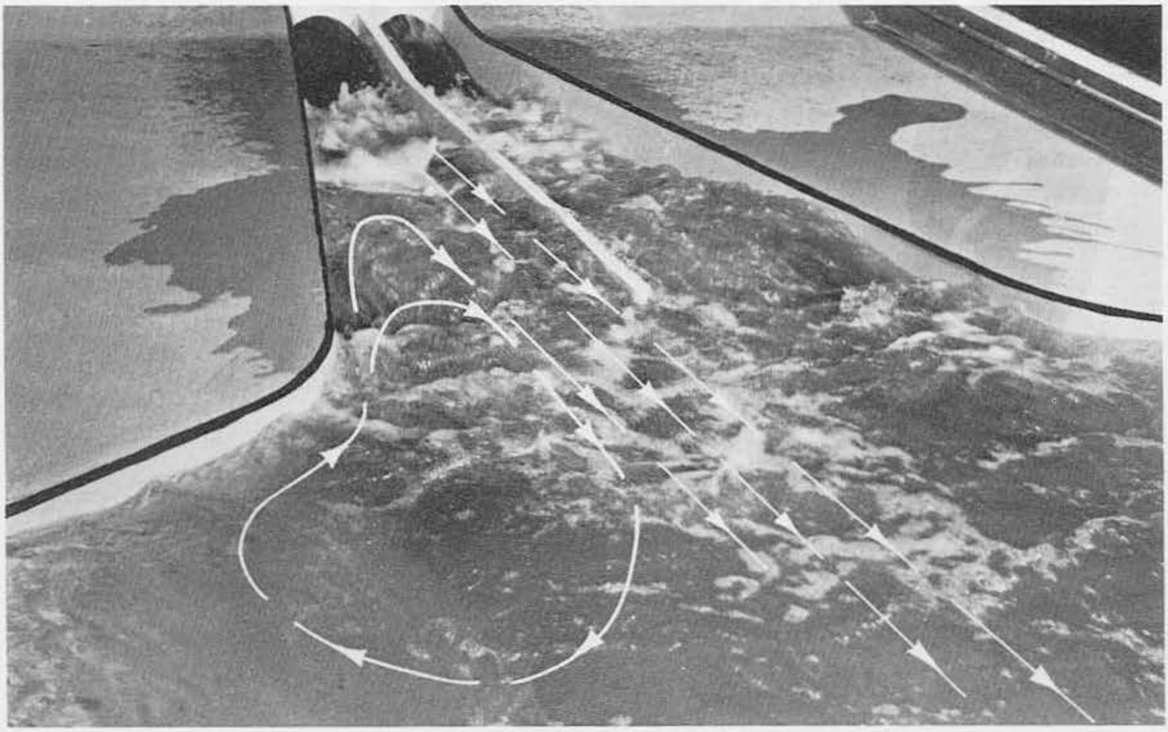


Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00

Photograph 1. Flow in original design stilling basin was downstream in direction along splitter wall and upstream along spray walls at low discharges

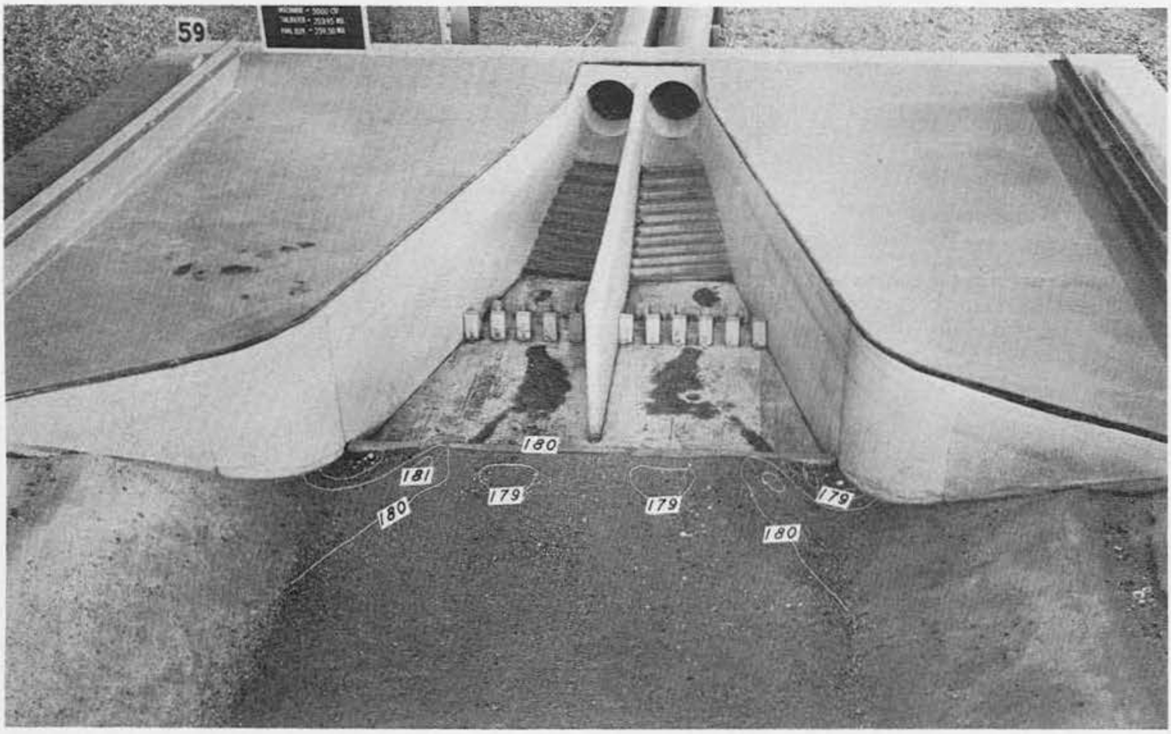


Discharge, 18,000 cfs; pool elev, 259.50; tailwater elev, 213.10

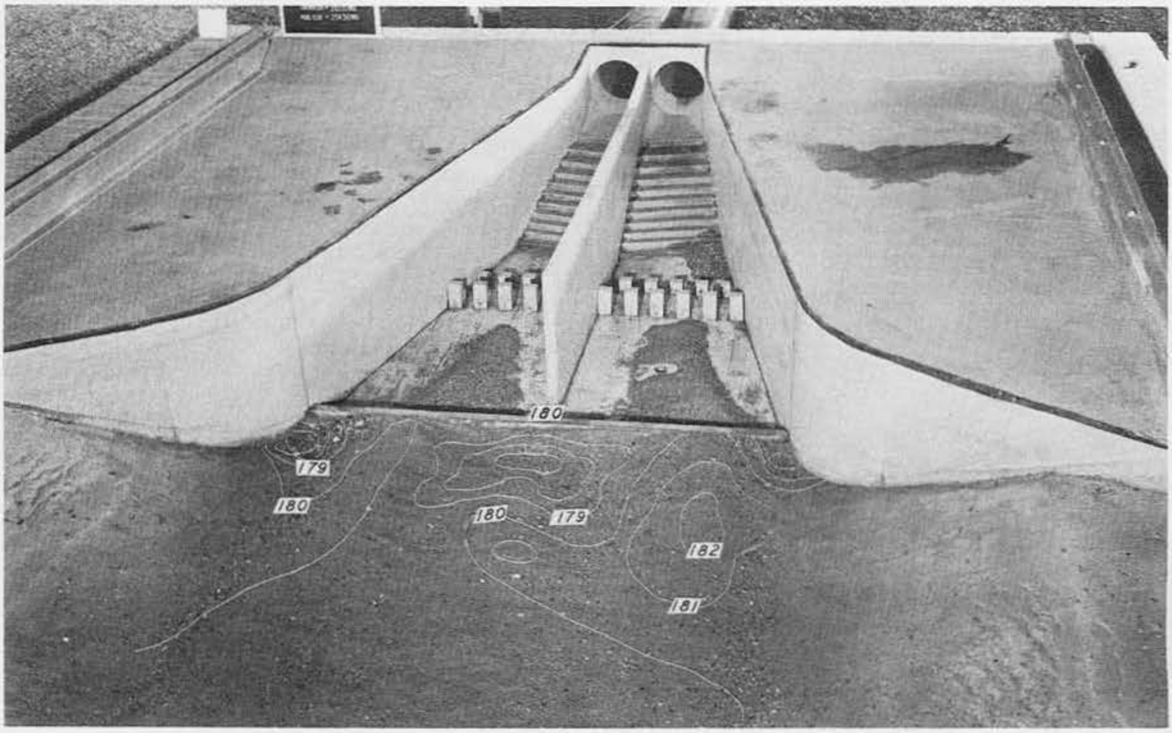


Discharge, 28,000 cfs; pool elev, 259.50; tailwater elev, 214.70

Photograph 2. Flow in original design stilling basin remained downstream in direction along splitter wall and upstream along spray walls at high discharges

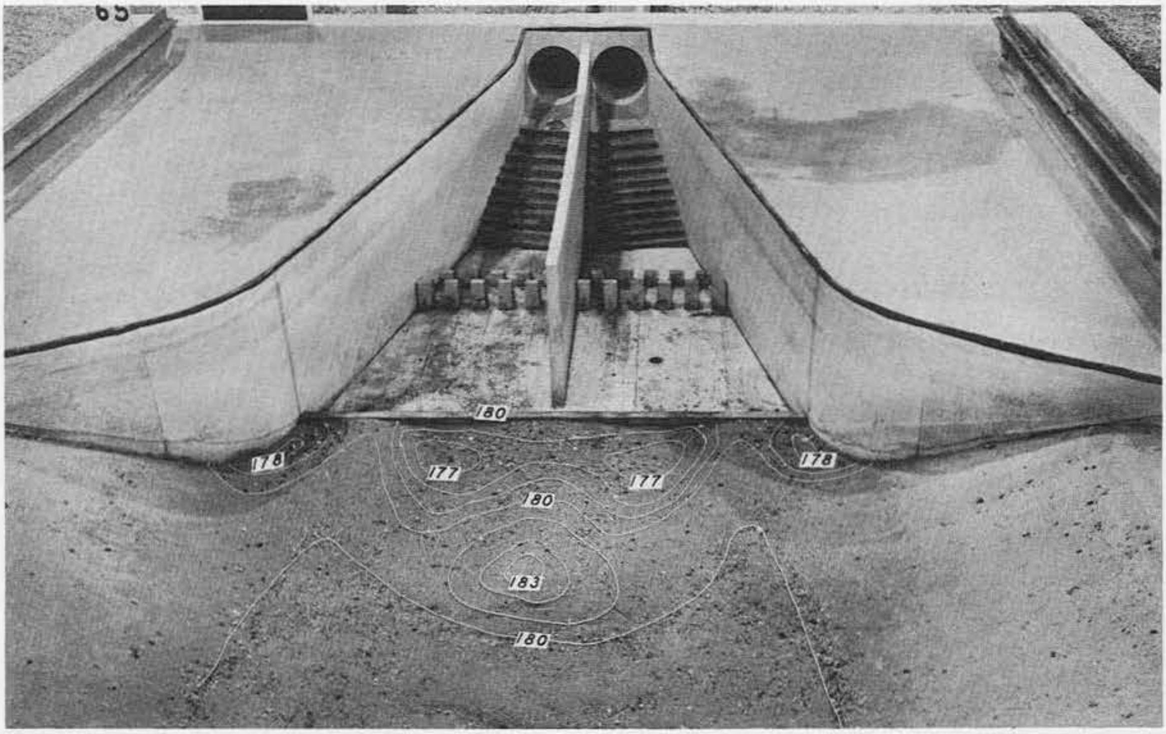


Discharge, 5,000 cfs; pool elev, 259.50; tailwater elev, 203.95

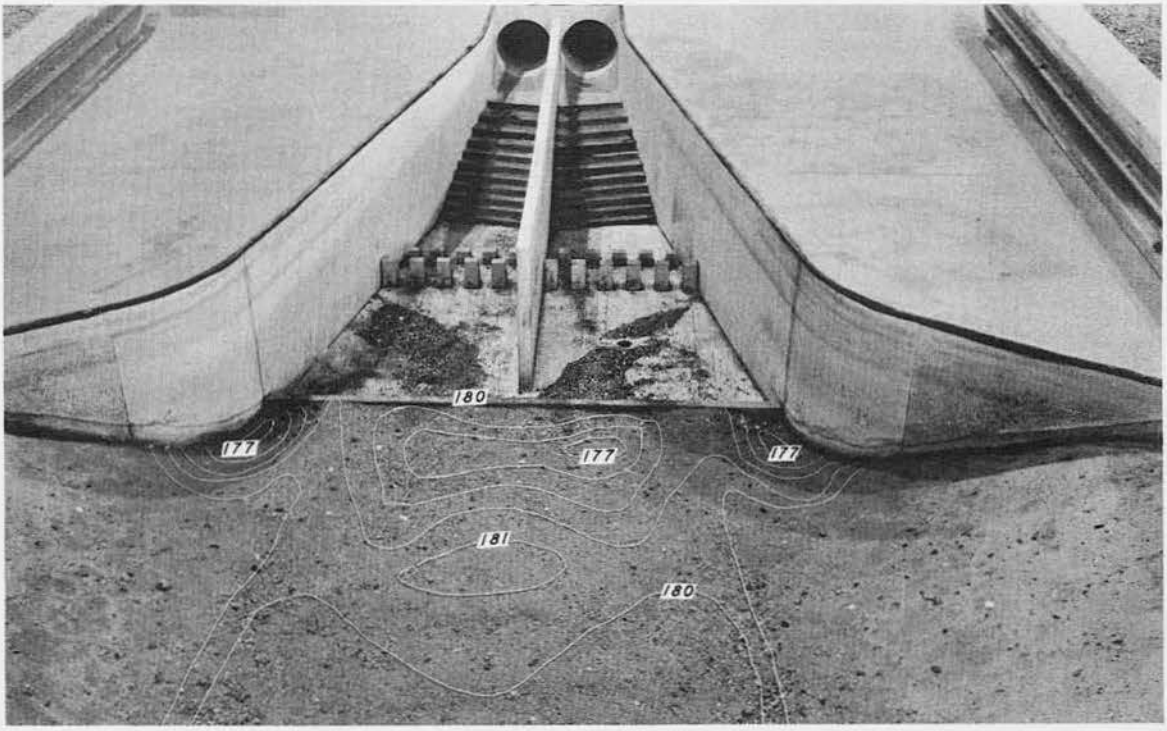


Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00

Photograph 3. Scour in exit channel caused by low discharges through original design stilling basin

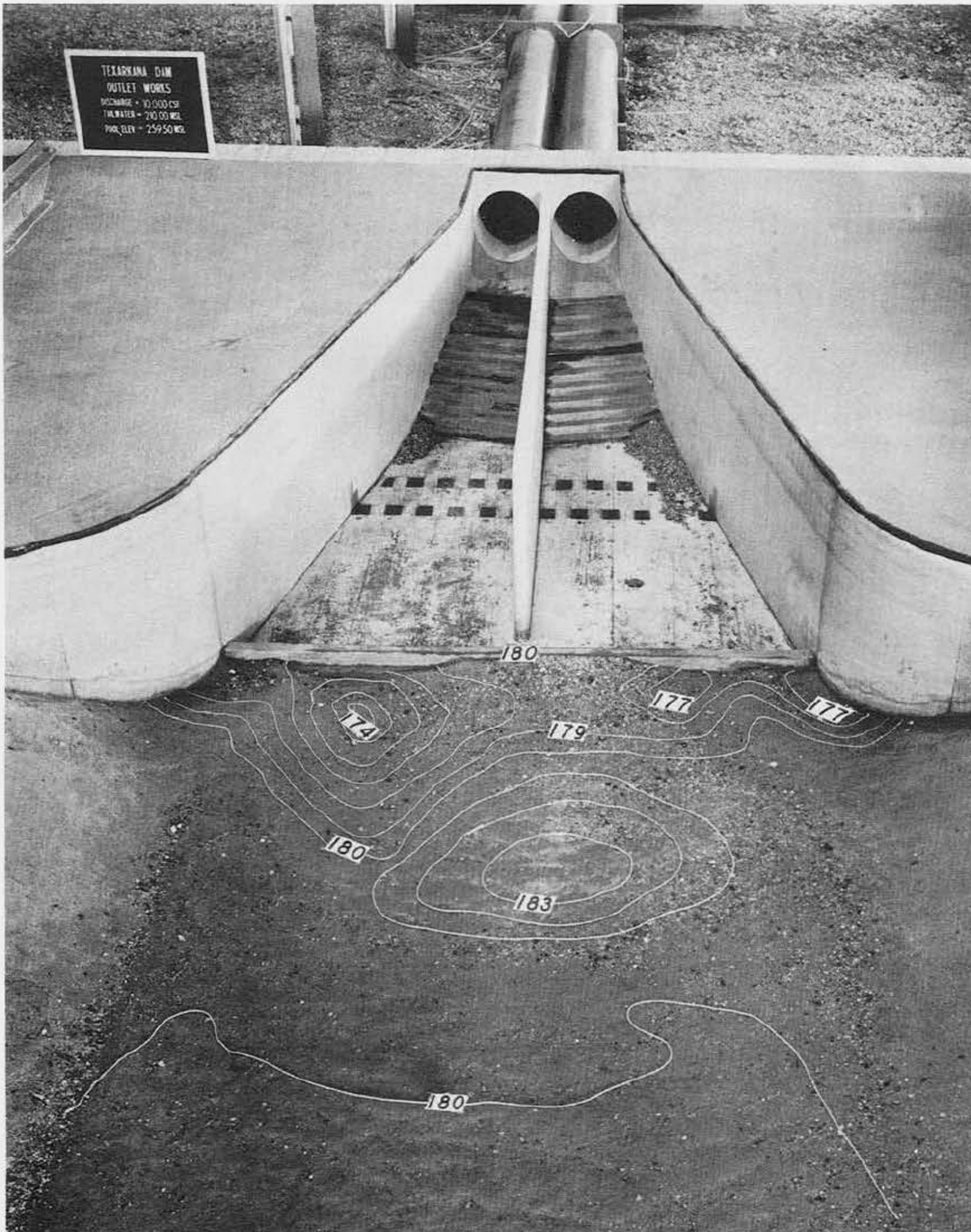


Discharge, 18,000 cfs; pool elev, 259.50; tailwater elev, 213.10



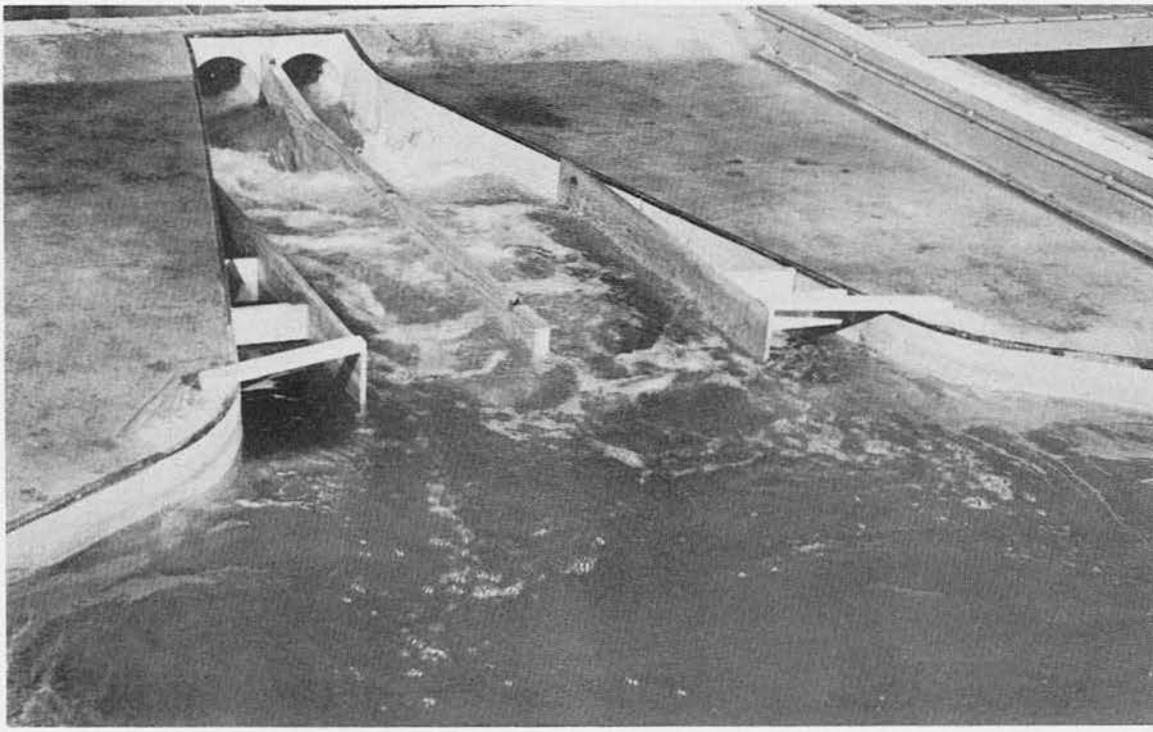
Discharge, 28,000 cfs; pool elev, 259.50; tailwater elev, 214.70

Photograph 4. Scour in exit channel caused by high discharges through original design stilling basin

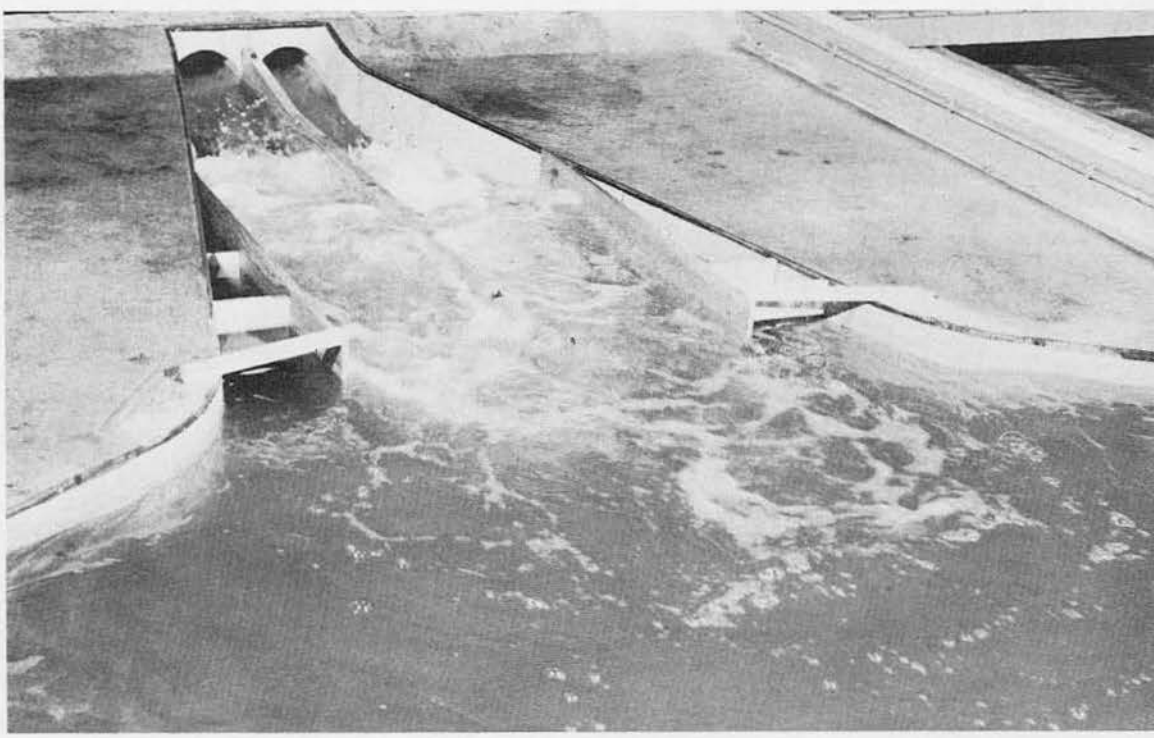


Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00

Photograph 5. Scour in exit channel caused by low discharges through original design stilling basin with baffle piers removed

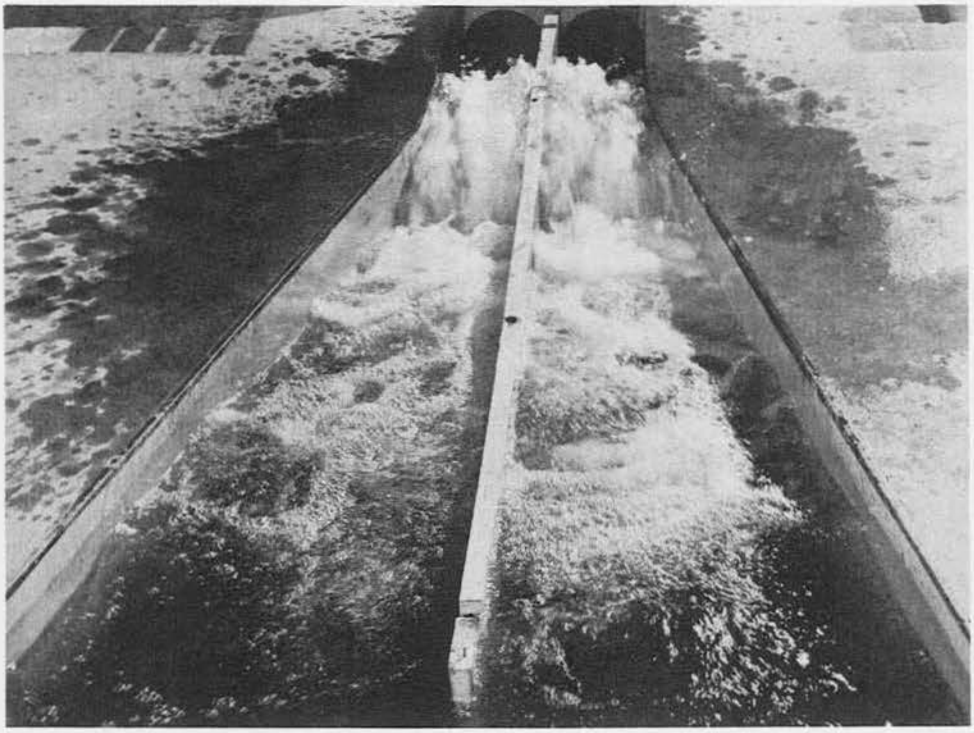


Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00

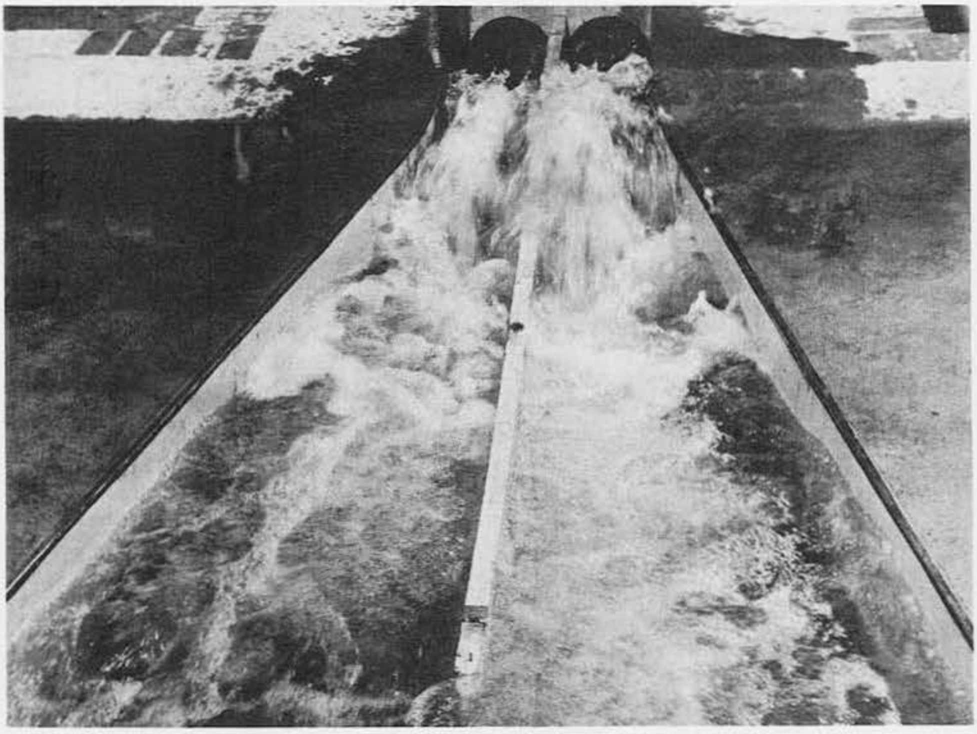


Discharge, 18,000 cfs; pool elev, 259.50; tailwater elev, 213.10

Photograph 6. Flow conditions with basin width at end sill decreased by 44.5 ft

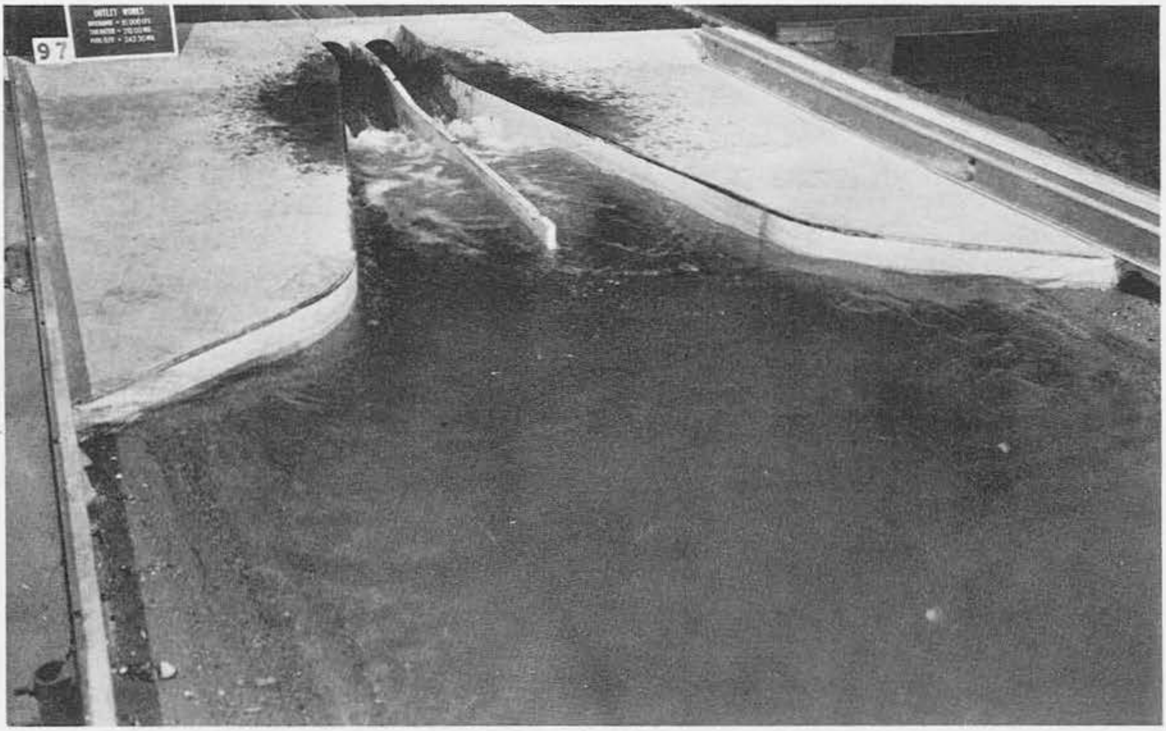


Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00

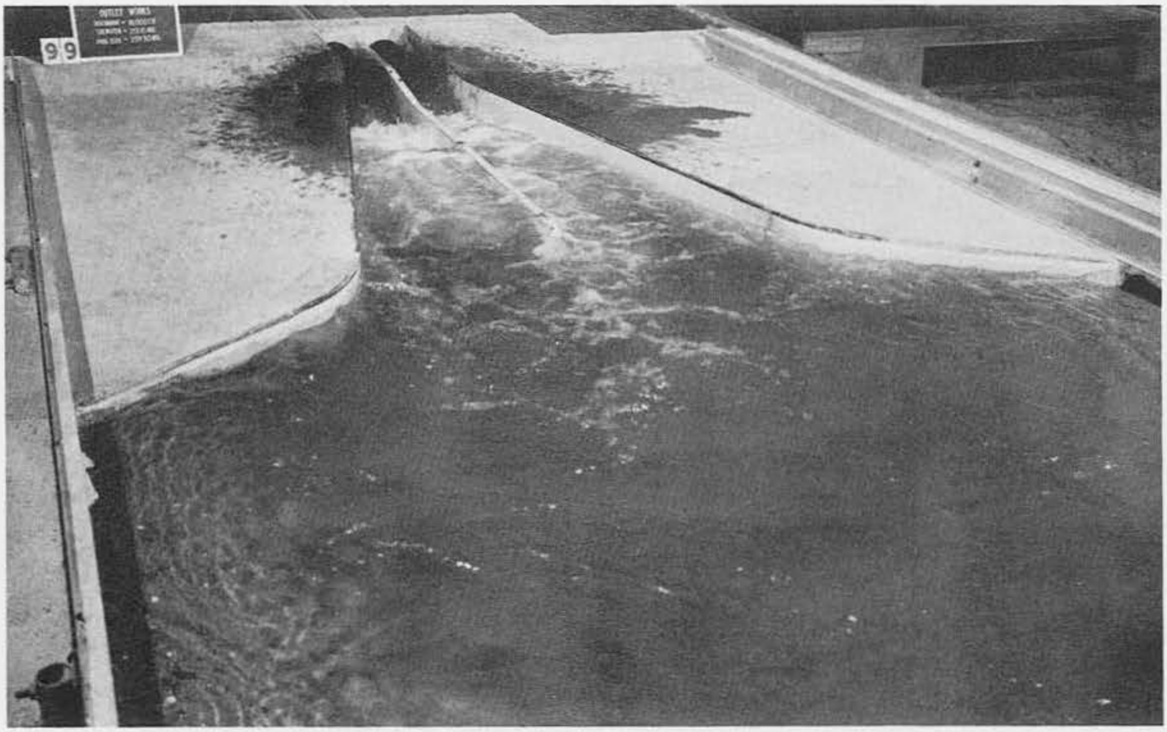


Discharge, 18,000 cfs; pool elev, 259.50; tailwater elev, 213.10

Photograph 7. Flow conditions with broad-crested weirs installed in stilling basin

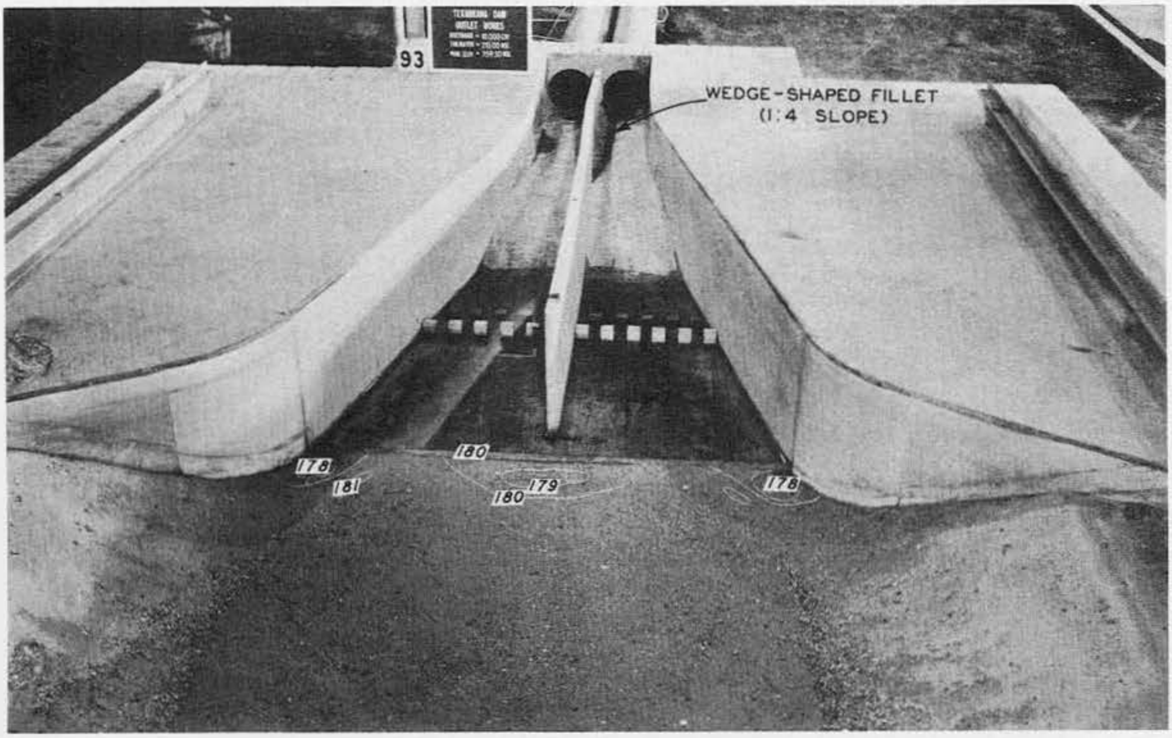


Discharge, 10,000 cfs; pool elev, 242.50; tailwater elev, 210.00

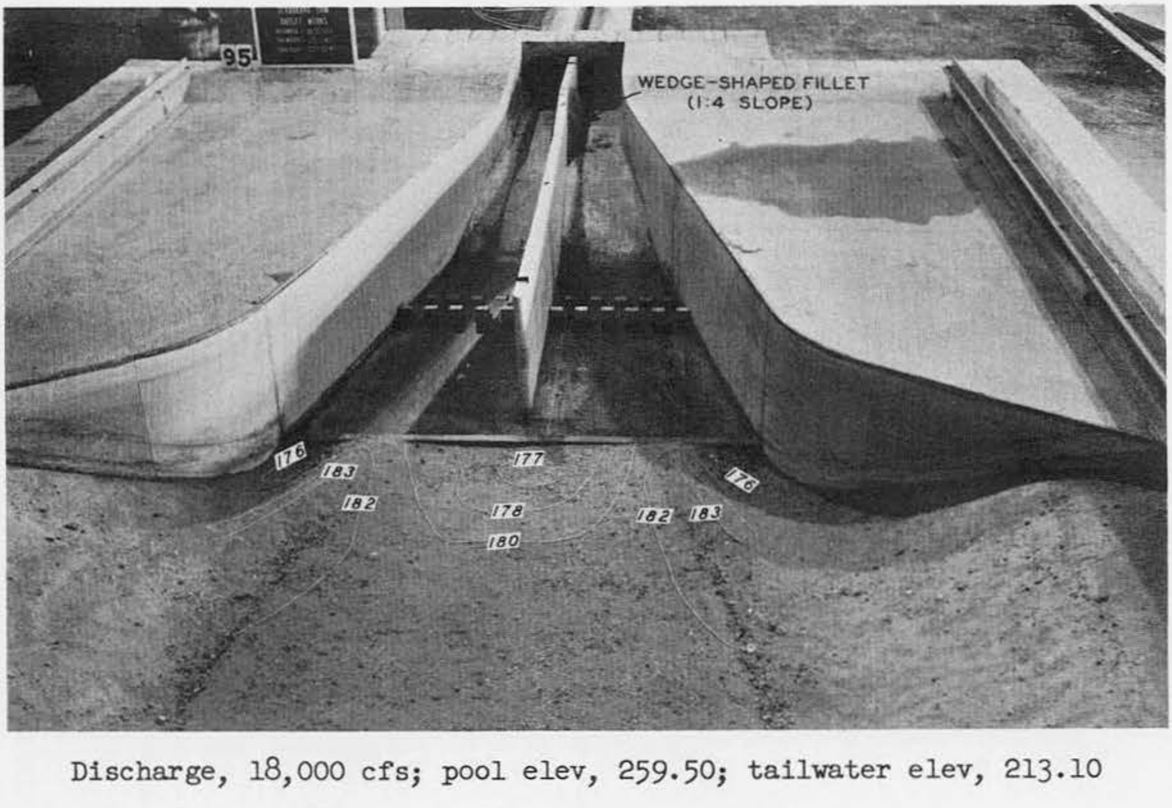


Discharge, 18,000 cfs; pool elev, 259.50; tailwater elev, 213.10

Photograph 8. Flow conditions with wedge-shaped fillet placed adjacent to splitter wall

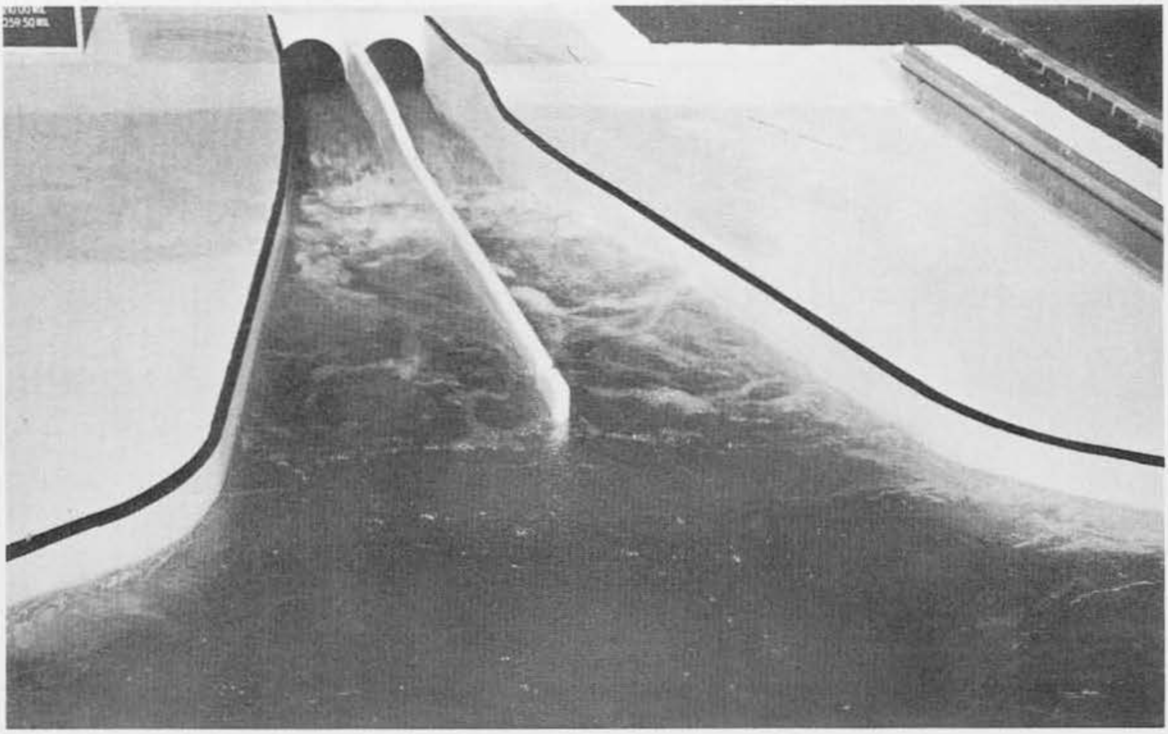


Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00

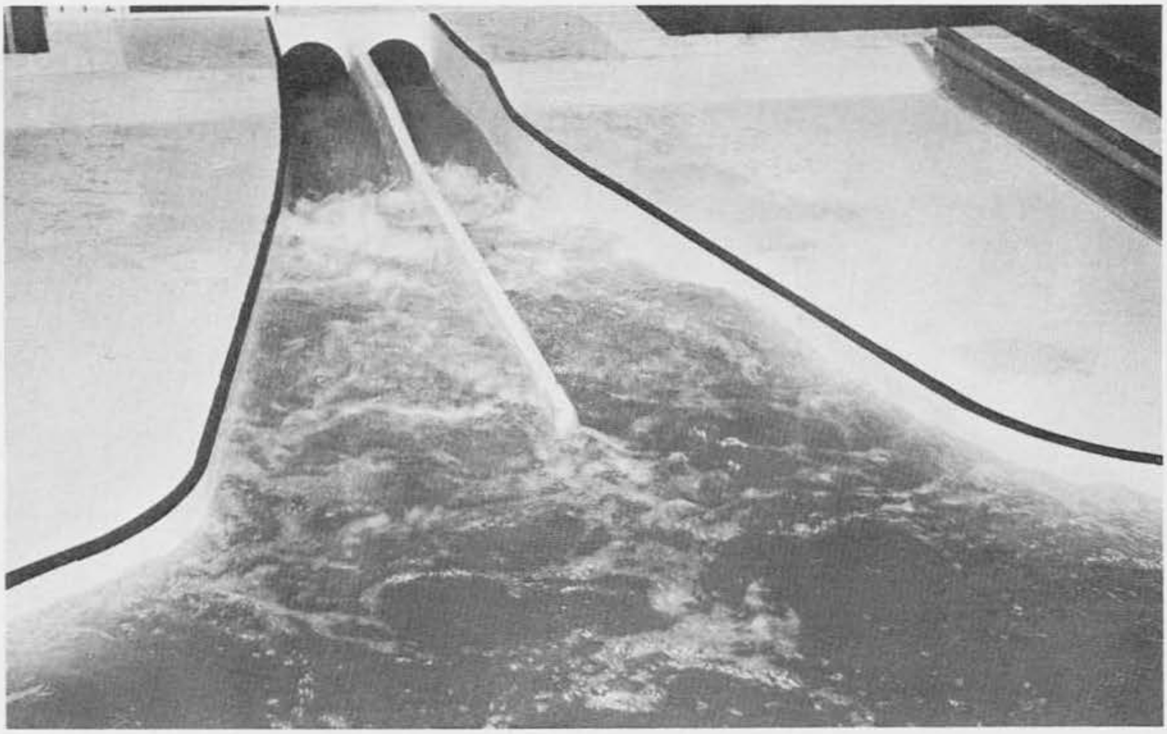


Discharge, 18,000 cfs; pool elev, 259.50; tailwater elev, 213.10

Photograph 9. Scour caused by flow with wedge-shaped fillets adjacent to splitter wall



Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00

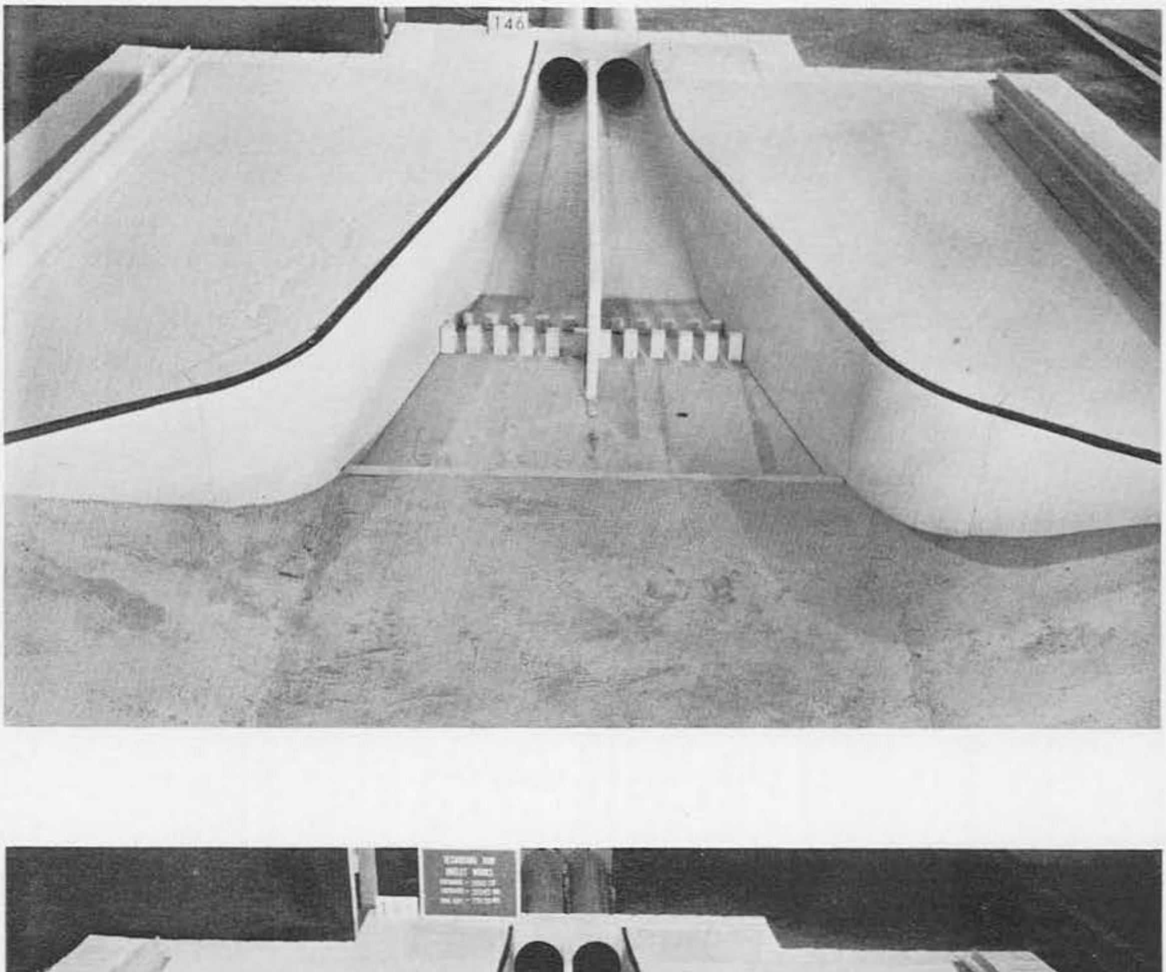


Discharge, 18,000 cfs; pool elev, 259.50; tailwater elev, 213.10

Photograph 10. Flow conditions with superelevation of basin floor and increased radius of curvature of spray walls

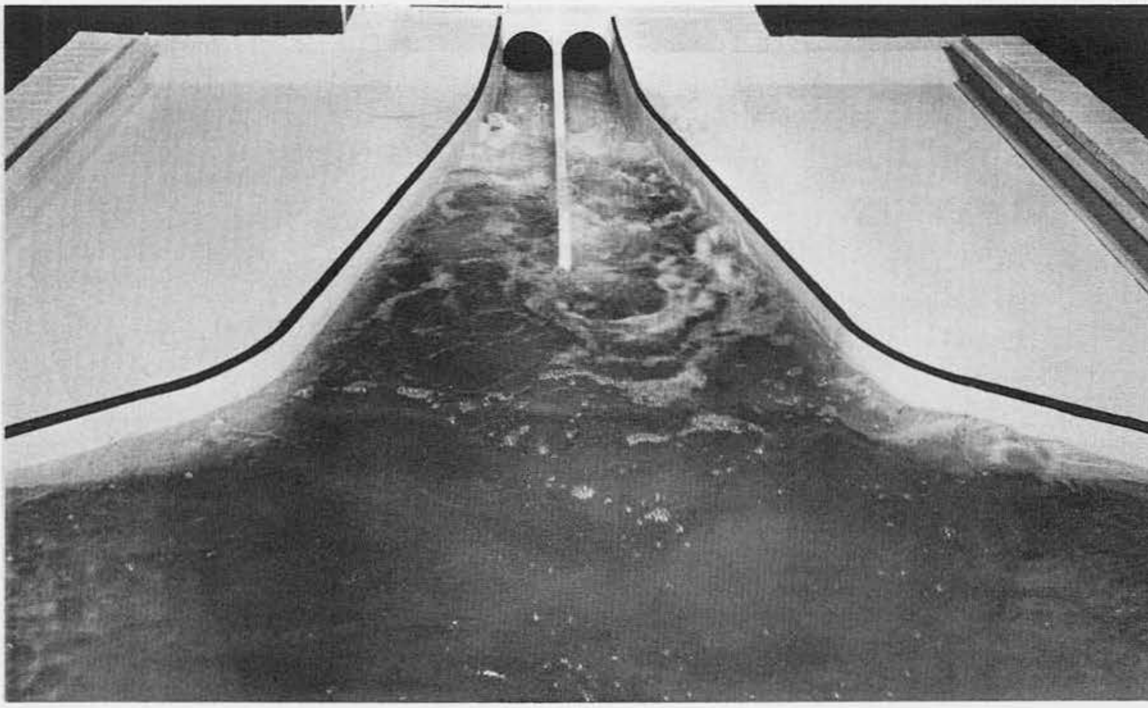
Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00

Photograph 11. Splitter wall removed

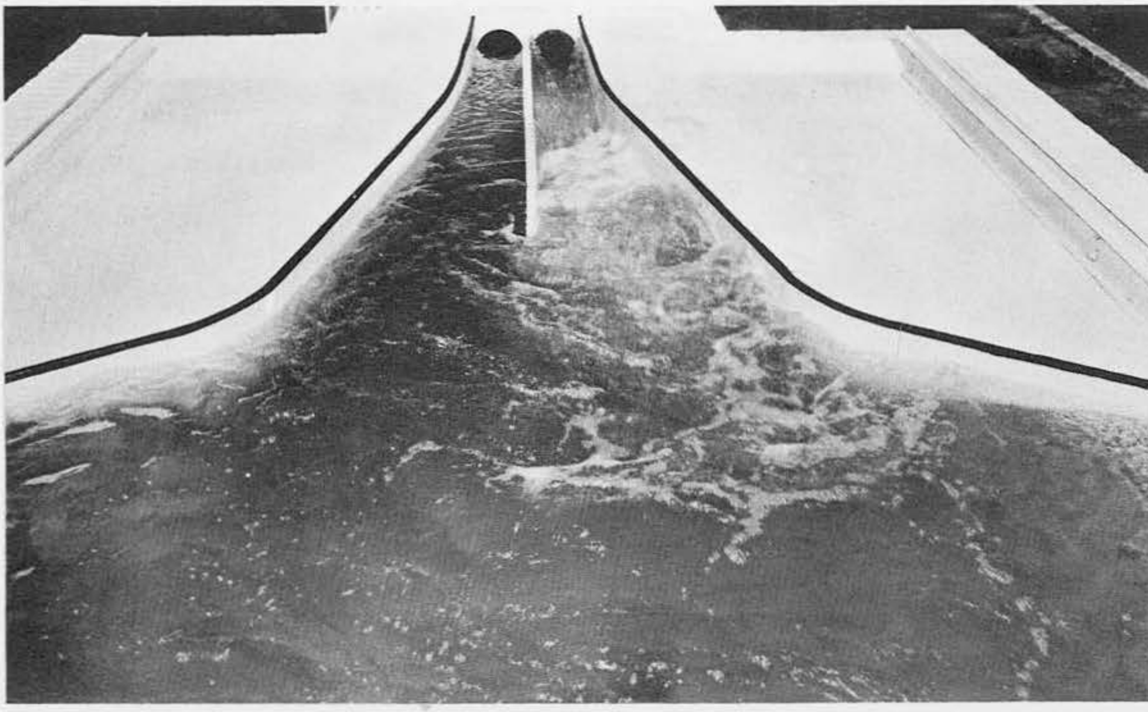


Discharge, 5,000 cfs; pool elev, 259.50; tailwater elev, 203.95

Photograph 12. Recommended stilling basin design

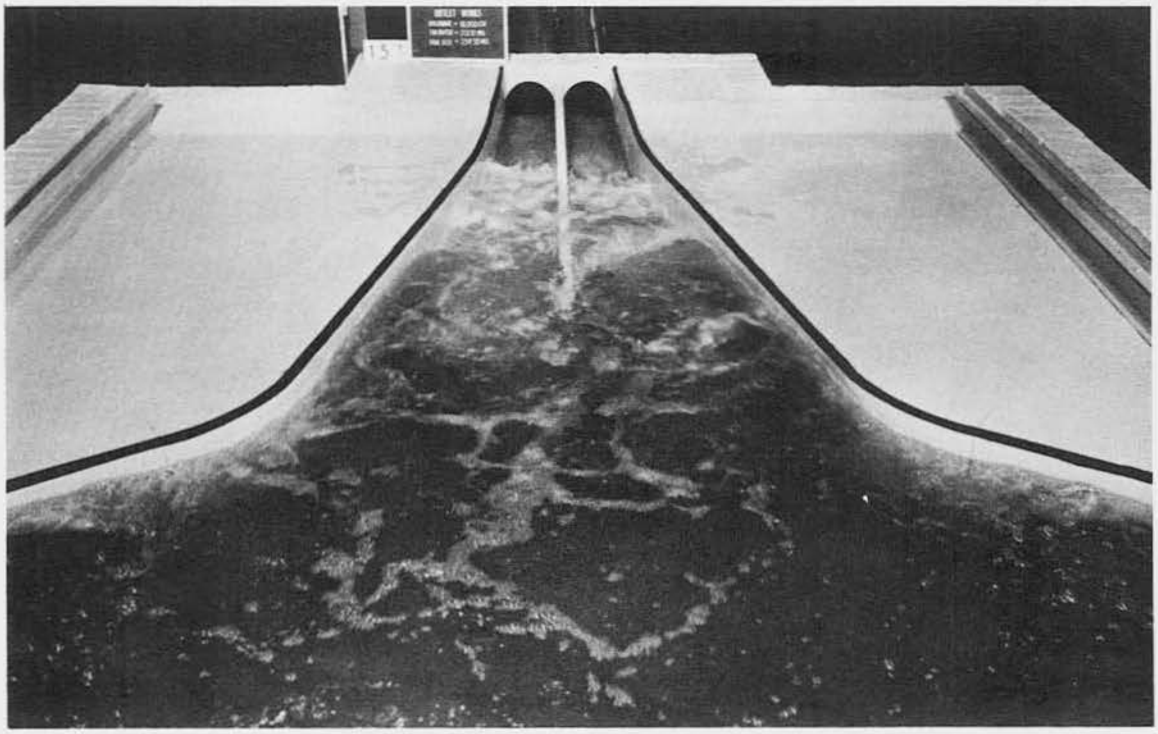


Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00
Twin conduit operation

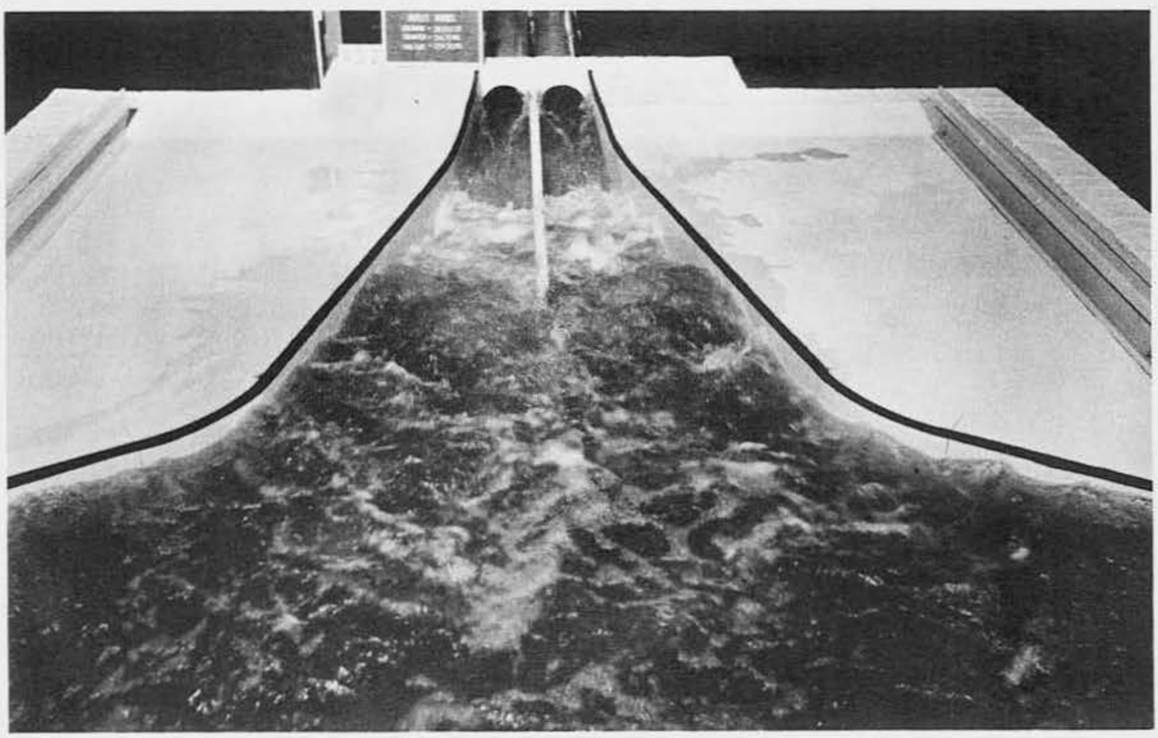


Discharge, 14,000 cfs; pool elev, 259.50; tailwater elev, 212.30
Single conduit operation

Photograph 13. Flow conditions in recommended design stilling basin with single and twin conduit operation

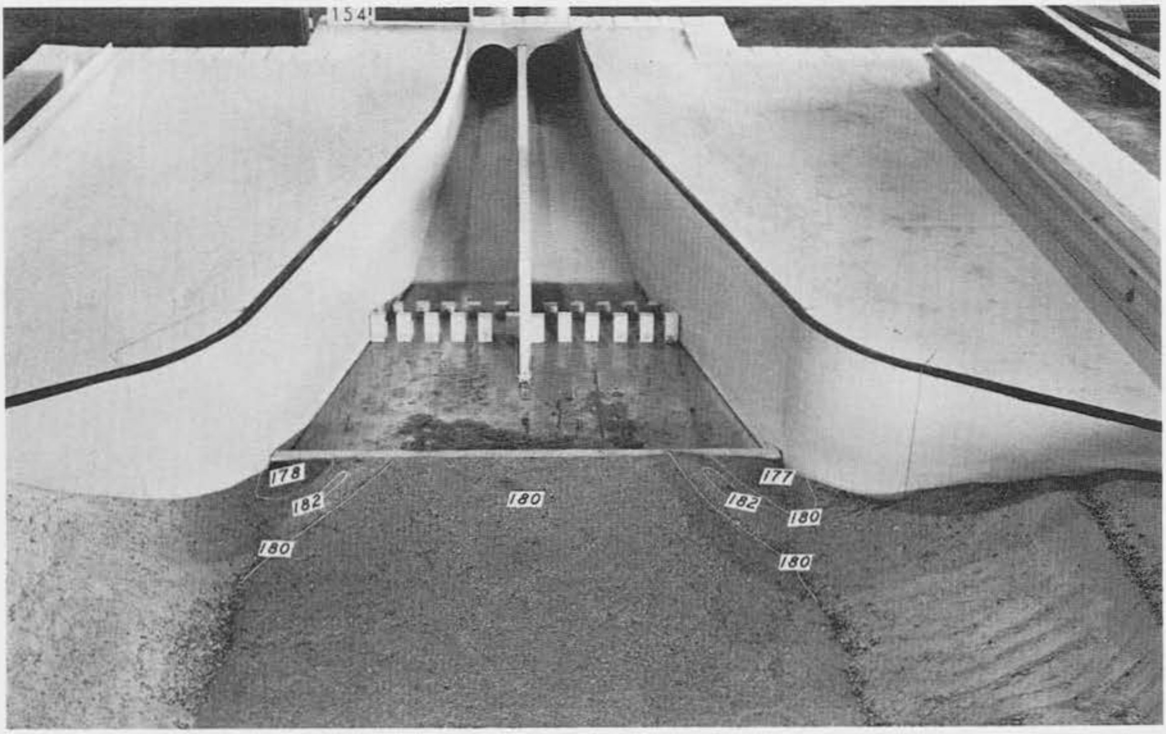


Discharge, 18,000 cfs; pool elev, 259.50; tailwater elev, 213.10

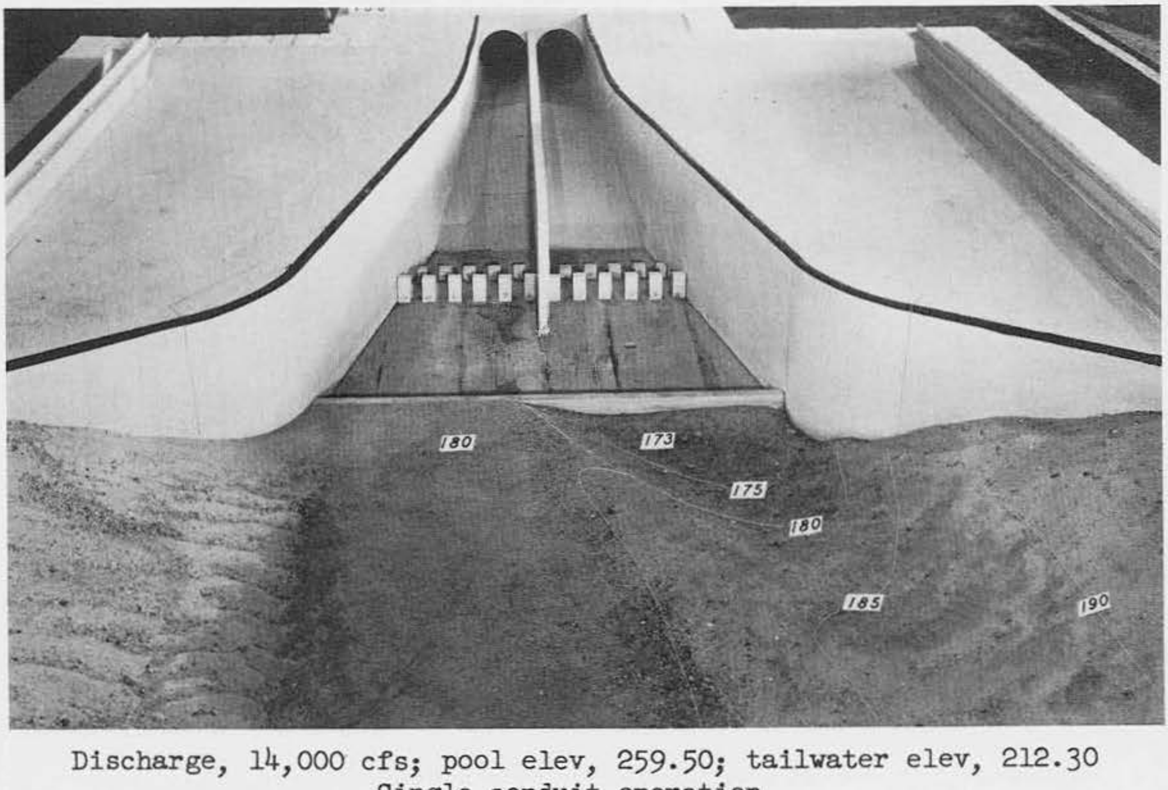


Discharge, 28,000 cfs; pool elev, 259.50; tailwater elev, 214.70

Photograph 14. Flow conditions in recommended design stilling basin for high discharges

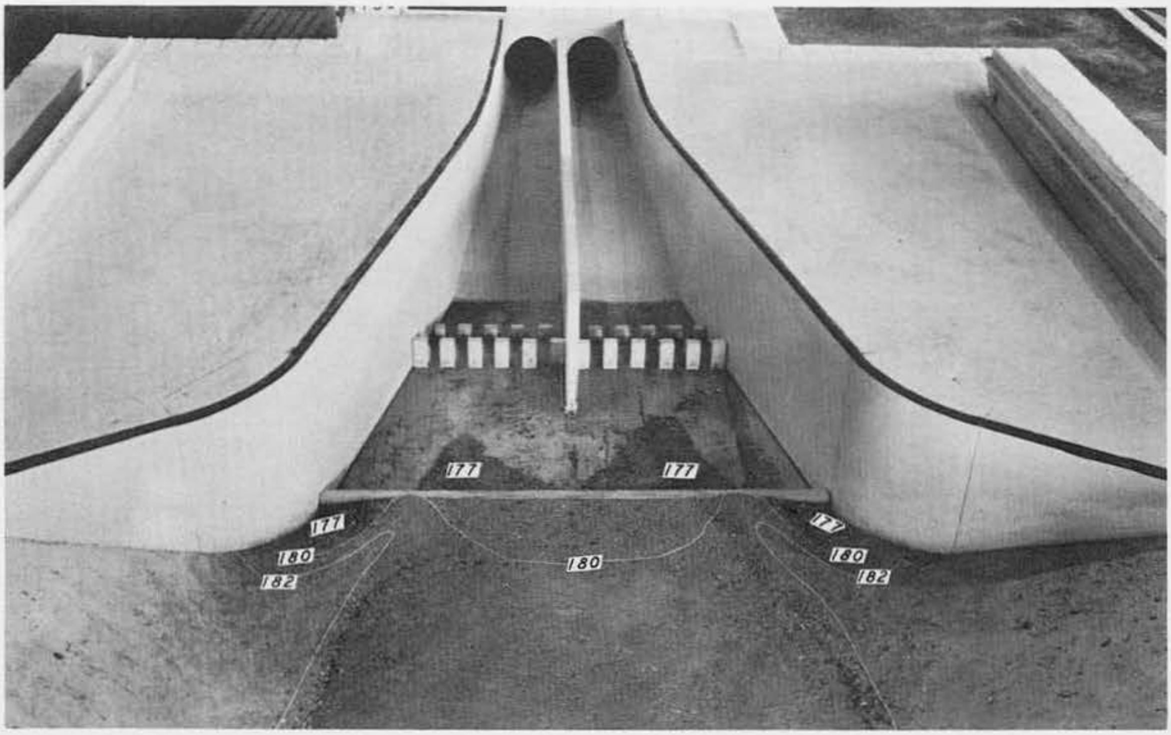


Discharge, 10,000 cfs; pool elev, 259.50; tailwater elev, 210.00
Twin conduit operation

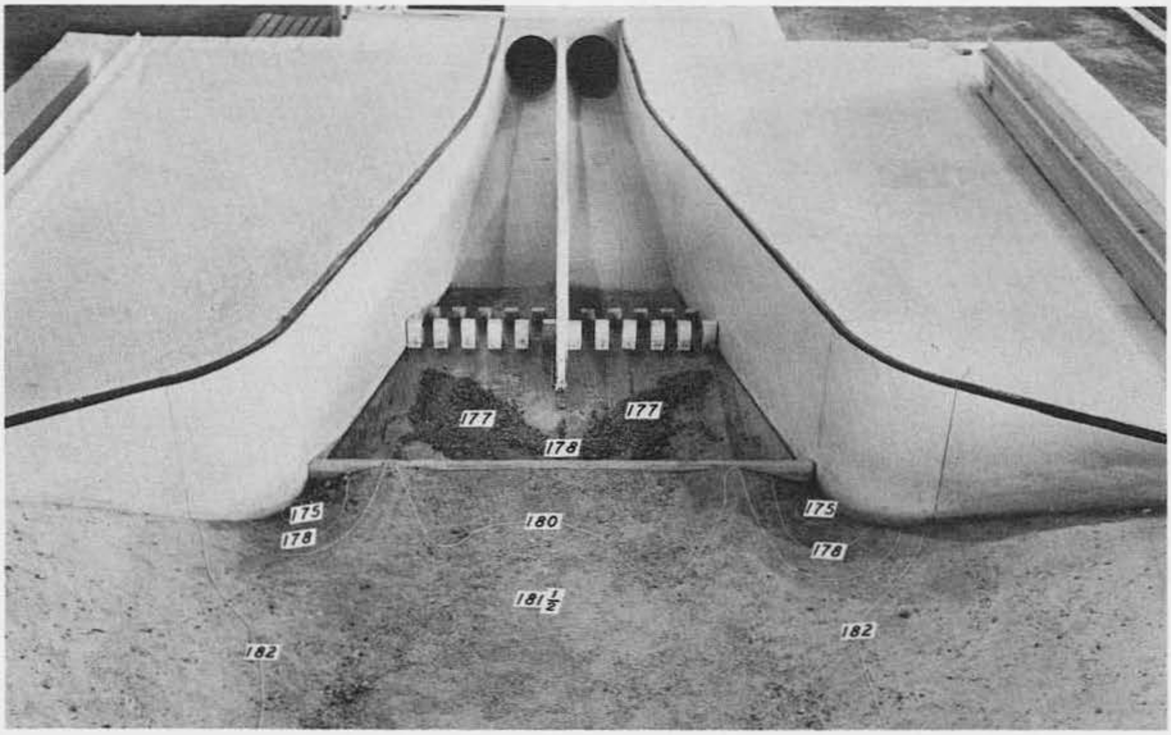


Discharge, 14,000 cfs; pool elev, 259.50; tailwater elev, 212.30
Single conduit operation

Photograph 15. Scour caused by discharge through recommended design stilling basin



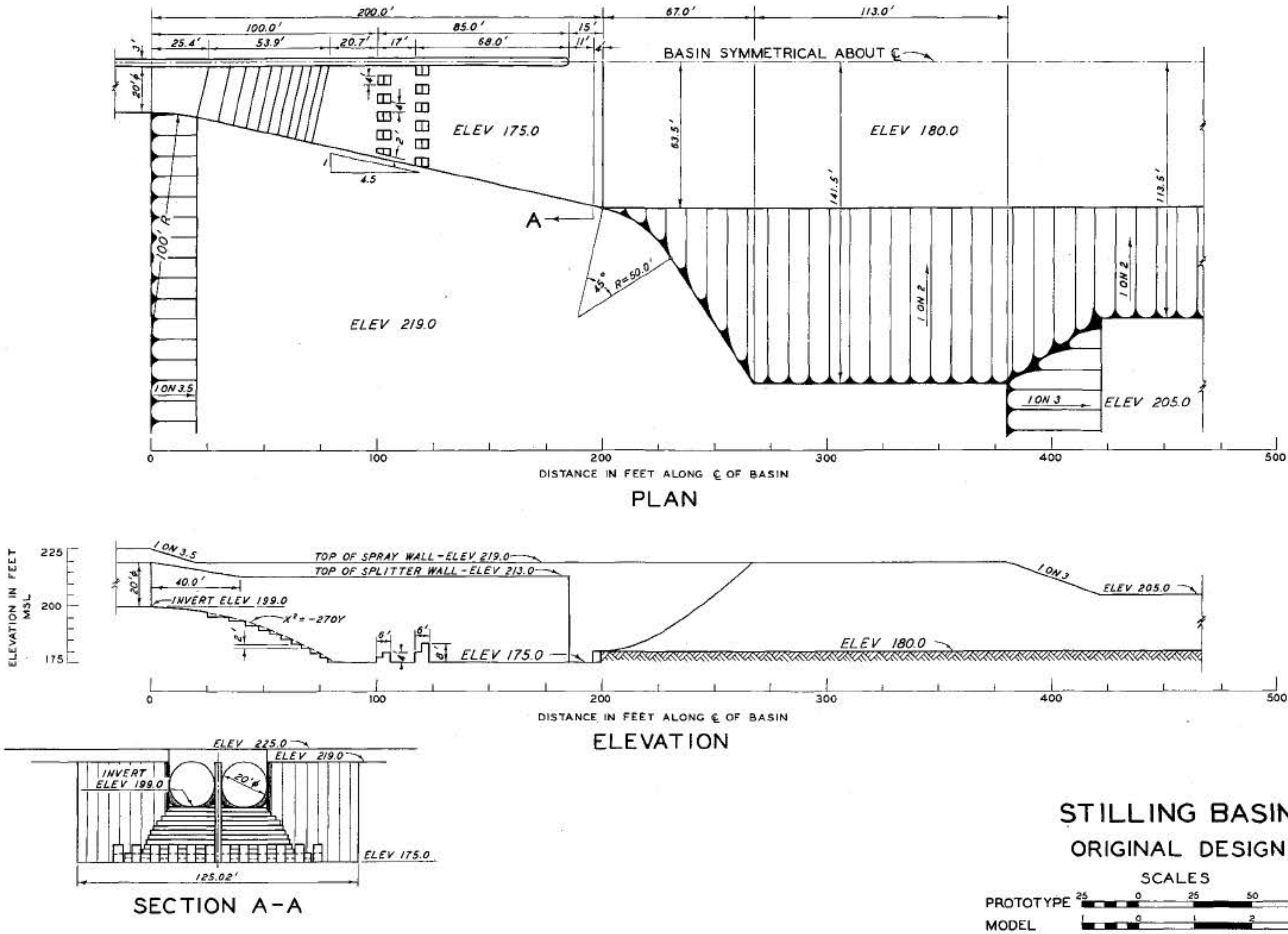
Discharge, 18,000 cfs; pool elev, 259.50; tailwater elev, 213.10



Discharge, 28,000 cfs; pool elev, 259.50; tailwater elev, 214.70

Photograph 16. Scour caused by discharge through recommended design stilling basin

PLATES



STILLING BASIN

ORIGINAL DESIGN

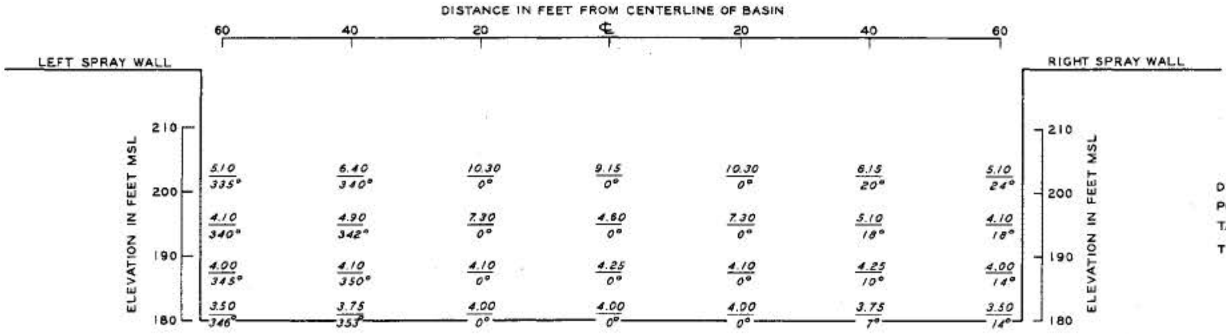
SCALES

PROTOTYPE 25 0 25 50 75 100 FT

MODEL 1 0 1 2 3 4 FT

PLATE 1

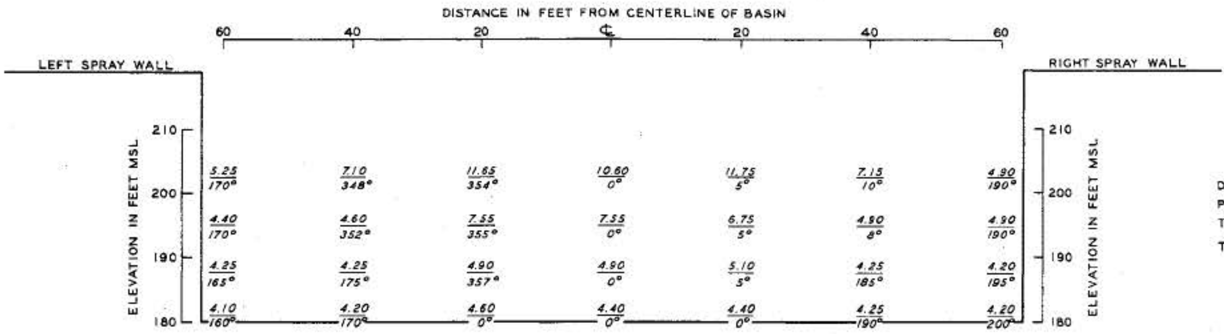
PLATE 2



TEST CONDITIONS

DISCHARGE	5,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	203.95

TWO CONDUITS OPERATING



TEST CONDITIONS

DISCHARGE	10,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	210.00

TWO CONDUITS OPERATING

NOTE: FIGURE ABOVE LINE IS VELOCITY IN PROTOTYPE FEET PER SECOND.
FIGURE BELOW LINE INDICATES ANGLE OF FLOW MEASURED CLOCKWISE FROM DOWNSTREAM DIRECTION.

VELOCITIES AT END SILL
ORIGINAL DESIGN
5,000 CFS – 10,000 CFS

DISTANCE IN FEET FROM CENTERLINE OF BASIN

LEFT SPRAY WALL — RIGHT SPRAY WALL

ELEVATION IN FEET MSL (180–210)

60	40	20	℄	20	40	60
4.90 / 170°	9.40 / 340°	14.90 / 348°	14.35 / 0°	14.35 / 12°	10.25 / 20°	5.10 / 190°
5.10 / 167°	6.40 / 342°	13.75 / 0°	14.35 / 0°	12.55 / 0°	7.85 / 18°	5.25 / 194°
4.90 / 168°	4.90 / 353°	10.25 / 0°	13.15 / 0°	9.40 / 0°	4.90 / 10°	4.60 / 190°
4.25 / 167°	4.60 / 172°	6.40 / 0°	12.00 / 0°	8.15 / 0°	4.25 / 187°	4.25 / 194°
4.10 / 167°	4.25 / 172°	4.25 / 0°	5.25 / 0°	4.25 / 0°	4.25 / 187°	4.25 / 194°

TEST CONDITIONS

DISCHARGE	15,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	212.45

TWO CONDUITS OPERATING

DISTANCE IN FEET FROM CENTERLINE OF BASIN

LEFT SPRAY WALL — RIGHT SPRAY WALL

ELEVATION IN FEET MSL (180–210)

60	40	20	℄	20	40	60
7.40 / 336°	9.45 / 348°	13.70 / 0°	11.10 / 0°	13.15 / 0°	9.45 / 12°	7.40 / 24°
6.40 / 167°	6.40 / 348°	12.55 / 0°	11.35 / 0°	12.10 / 0°	6.00 / 12°	6.40 / 194°
4.90 / 167°	4.90 / 174°	9.45 / 0°	11.25 / 0°	10.30 / 0°	4.90 / 187°	4.90 / 194°
4.60 / 167°	4.60 / 174°	7.40 / 0°	10.30 / 0°	7.60 / 0°	4.60 / 187°	4.60 / 194°
4.25 / 167°	4.40 / 174°	4.60 / 0°	5.35 / 0°	4.60 / 0°	4.25 / 187°	4.25 / 194°

TEST CONDITIONS

DISCHARGE	18,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	213.10

TWO CONDUITS OPERATING

DISTANCE IN FEET FROM CENTERLINE OF BASIN

LEFT SPRAY WALL — RIGHT SPRAY WALL

ELEVATION IN FEET MSL (180–210)

60	40	20	℄	20	40	60
14.35 / 346°	16.40 / 353°	16.90 / 0°	14.35 / 0°	16.90 / 0°	16.40 / 7°	14.35 / 14°
11.10 / 167°	11.75 / 353°	14.65 / 0°	11.10 / 0°	14.35 / 0°	11.75 / 7°	10.80 / 194°
4.90 / 167°	6.40 / 174°	10.85 / 0°	10.85 / 0°	11.10 / 0°	6.40 / 187°	4.90 / 194°
4.25 / 167°	4.25 / 174°	8.00 / 0°	9.45 / 0°	8.00 / 0°	4.40 / 187°	4.25 / 194°
3.75 / 167°	4.25 / 174°	4.60 / 0°	4.90 / 0°	4.10 / 0°	4.10 / 187°	3.75 / 194°

TEST CONDITIONS

DISCHARGE	28,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	214.70

TWO CONDUITS OPERATING

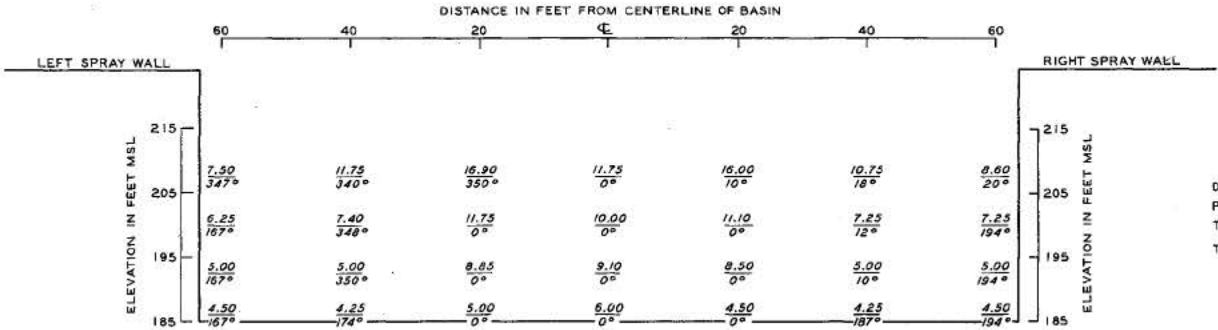
NOTE FIGURE ABOVE LINE IS VELOCITY IN PROTOTYPE FEET PER SECOND

FIGURE BELOW LINE INDICATES ANGLE OF FLOW MEASURED CLOCKWISE FROM DOWNSTREAM DIRECTION

VELOCITIES AT END SILL

ORIGINAL DESIGN

15,000 CFS, 18,000 CFS AND 28,000 CFS

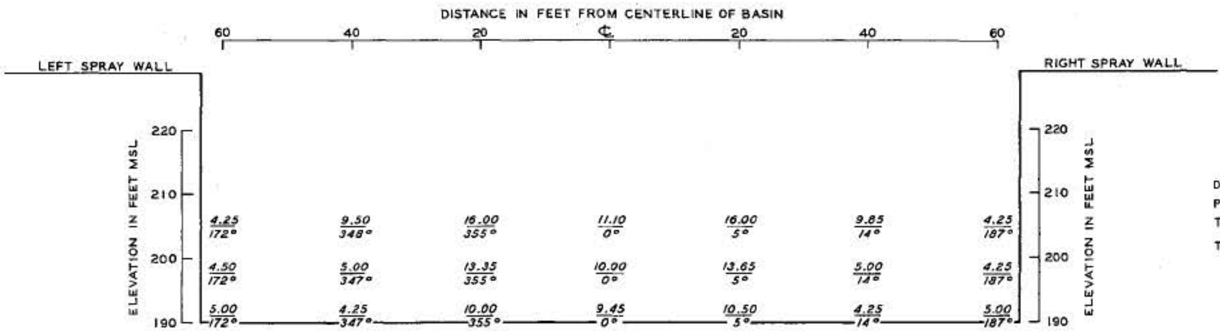


BASIN FLOOR AND END SILL RAISED 5 FT

TEST CONDITIONS

DISCHARGE	10,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	210.00

TWO CONDUITS OPERATING



BASIN FLOOR RAISED 5 FT
END SILL RAISED 10 FT

TEST CONDITIONS

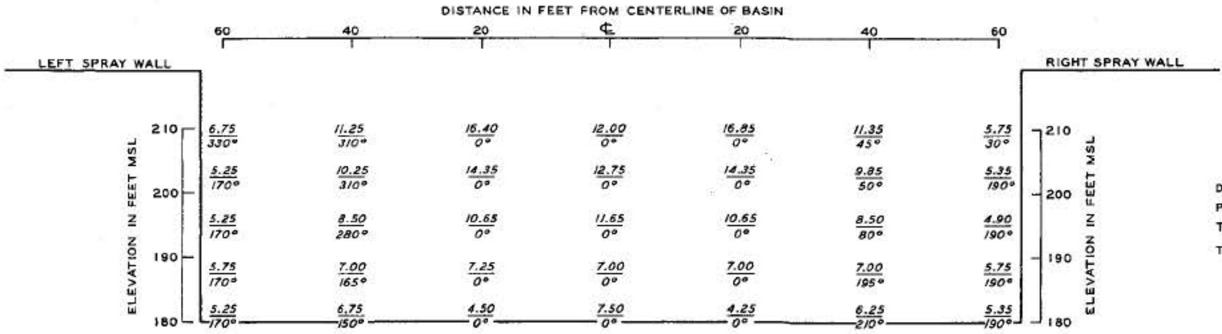
DISCHARGE	10,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	210.00

TWO CONDUITS OPERATING

NOTE: FIGURE ABOVE LINE IS VELOCITY IN PROTOTYPE FEET PER SECOND.

FIGURE BELOW LINE INDICATES ANGLE OF FLOW MEASURED CLOCKWISE FROM DOWNSTREAM DIRECTION.

EFFECT OF STILLING BASIN AND END SILL ELEVATION ON VELOCITIES AT END SILL



STEPS FLARED AT ANGLE OF 120 DEGREES TO SPRAY WALLS

NOTE: FIGURE ABOVE LINE IS VELOCITY IN PROTOTYPE FEET PER SECOND.
FIGURE BELOW LINE INDICATES ANGLE OF FLOW MEASURED CLOCKWISE FROM DOWNSTREAM DIRECTION.

TEST CONDITIONS

DISCHARGE	10,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	210.00
TWO CONDUITS OPERATING	

EFFECT OF FLARE OF STEPS ON VELOCITIES AT END SILL

PLATE 6

DISTANCE IN FEET FROM CENTERLINE OF BASIN

LEFT SPRAY WALL — RIGHT SPRAY WALL

ELEVATION IN FEET MSL (180–210)

40	20	℄	20	40
9.25 / 0°	12.50 / 340°	11.00 / 0°	12.50 / 0°	9.00 / 15°
8.75 / 0°	10.60 / 0°	8.50 / 0°	10.25 / 0°	8.50 / 0°
5.00 / 0°	6.25 / 0°	8.00 / 0°	5.85 / 0°	4.75 / 0°
3.60 / 0°	5.00 / 0°	7.75 / 0°	4.75 / 0°	3.25 / 0°
3.25 / 0°	3.60 / 0°	7.75 / 0°	3.60 / 0°	3.90 / 0°

TEST CONDITIONS

DISCHARGE 10,000 CFS
POOL ELEVATION 259.50
TAILWATER ELEVATION 210.00
TWO CONDUITS OPERATING

DISTANCE IN FEET FROM CENTERLINE OF BASIN

LEFT SPRAY WALL — RIGHT SPRAY WALL

ELEVATION IN FEET MSL (180–210)

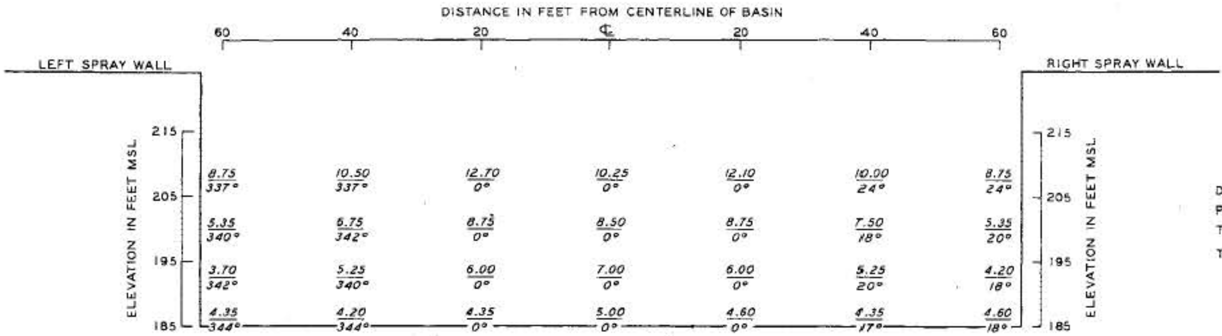
40	20	℄	20	40
10.74 / 0°	12.50 / 0°	12.50 / 0°	12.50 / 0°	10.74 / 0°
10.25 / 0°	14.00 / 0°	12.50 / 0°	14.00 / 0°	10.25 / 0°
7.50 / 0°	12.50 / 0°	11.20 / 0°	12.50 / 0°	7.50 / 0°
6.75 / 0°	11.74 / 0°	12.50 / 0°	11.74 / 0°	6.75 / 0°
4.75 / 0°	11.74 / 0°	11.74 / 0°	11.50 / 0°	4.75 / 0°

TEST CONDITIONS

DISCHARGE 18,000 CFS
POOL ELEVATION 259.50
TAILWATER ELEVATION 213.10
TWO CONDUITS OPERATING

NOTE: FIGURE ABOVE LINE IS VELOCITY IN PROTOTYPE FEET PER SECOND.
FIGURE BELOW LINE INDICATES ANGLE OF FLOW MEASURED CLOCKWISE FROM DOWNSTREAM DIRECTION.

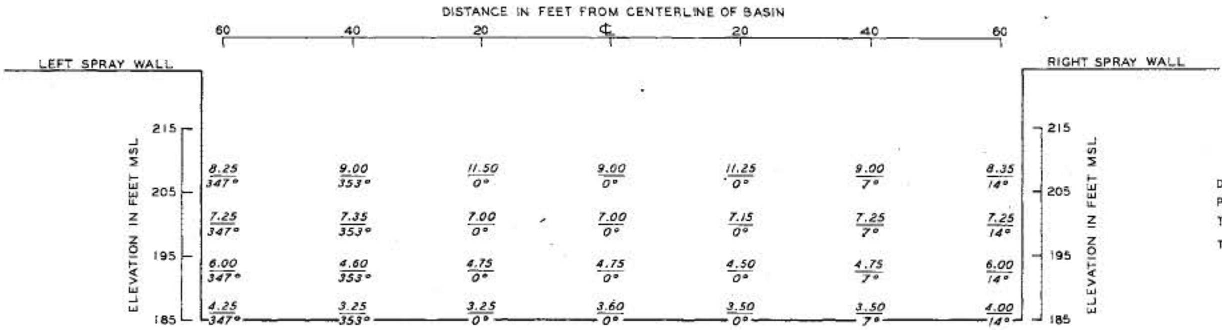
EFFECT OF REDUCTION IN WIDTH OF STILLING BASIN ON VELOCITIES AT END SILL



DEFLECTOR BLOCKS - TYPE C

TEST CONDITIONS

DISCHARGE	10,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	210.00
TWO CONDUITS OPERATING	



DEFLECTOR BLOCKS - TYPE D

TEST CONDITIONS

DISCHARGE	10,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	210.00
TWO CONDUITS OPERATING	

NOTE: FIGURE ABOVE LINE IS VELOCITY IN PROTOTYPE FEET PER SECOND.
FIGURE BELOW LINE INDICATES ANGLE OF FLOW MEASURED CLOCKWISE FROM DOWNSTREAM DIRECTION.

EFFECT OF DEFLECTOR BLOCKS AT CONDUIT EXIT PORTALS ON VELOCITIES AT END SILL

DISTANCE IN FEET FROM CENTERLINE OF BASIN

LEFT SPRAY WALL — RIGHT SPRAY WALL

ELEVATION IN FEET MSL (180, 190, 200, 210)

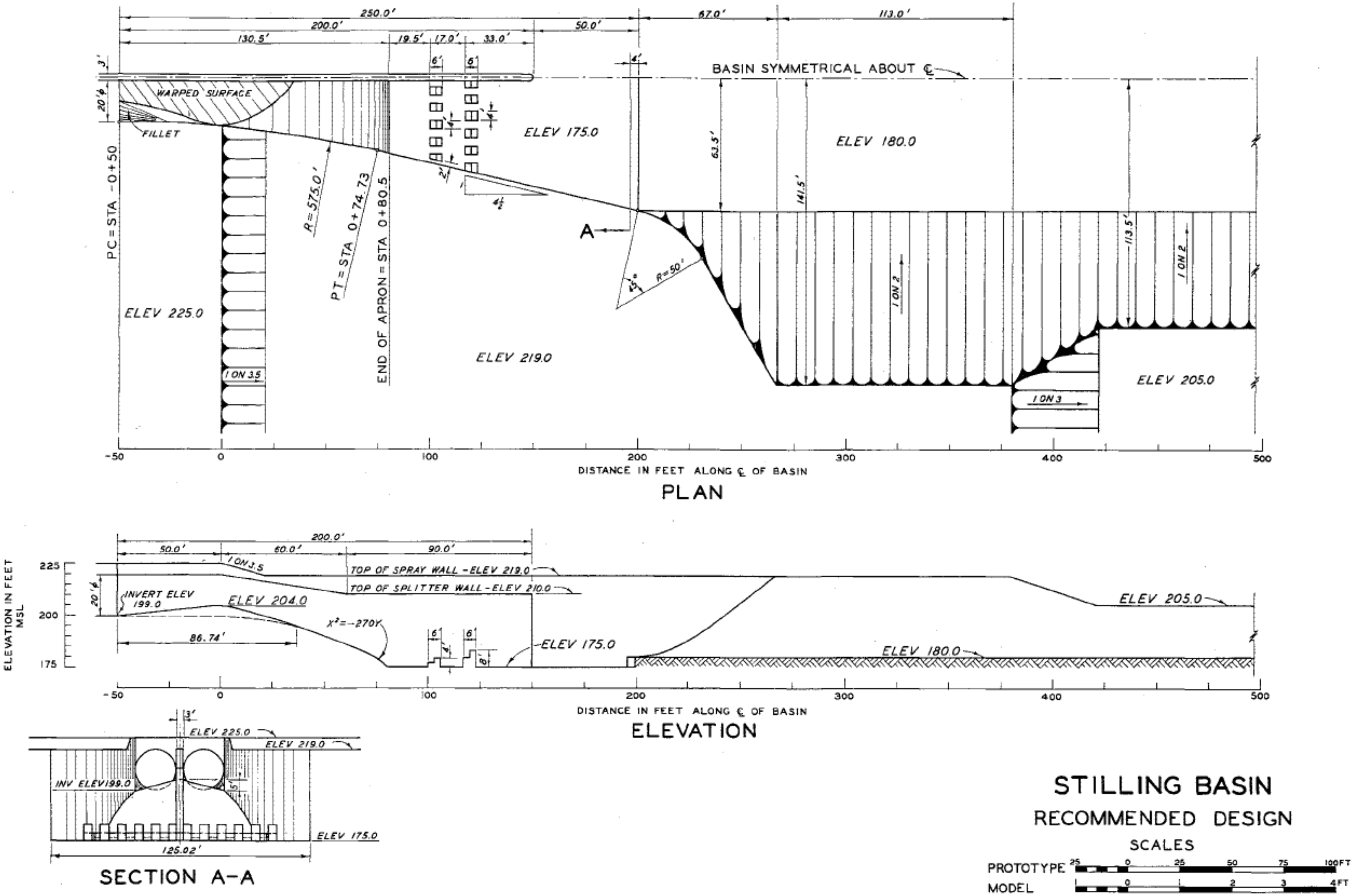
60	40	20	℄	20	40	60
10.25 / 347°	10.00 / 353°	10.00 / 0°	8.65 / 0°	10.00 / 0°	10.00 / 7°	10.25 / 14°
8.25 / 347°	8.25 / 357°	8.25 / 0°	7.60 / 0°	8.25 / 0°	8.25 / 4°	8.25 / 14°
5.75 / 350°	5.40 / 0°	4.75 / 0°	5.50 / 0°	4.75 / 0°	5.40 / 0°	5.75 / 12°
4.25 / 350°	3.75 / 350°	3.75 / 0°	4.50 / 0°	3.75 / 0°	3.75 / 10°	4.25 / 10°
3.75 / 345°	3.50 / 350°	3.25 / 340°	3.75 / 0°	3.25 / 20°	3.50 / 10°	3.75 / 15°

NOTE: FIGURE ABOVE LINE IS VELOCITY IN PROTOTYPE FEET PER SECOND.
FIGURE BELOW LINE INDICATES ANGLE OF FLOW MEASURED CLOCKWISE FROM DOWNSTREAM DIRECTION.

TEST CONDITIONS

DISCHARGE	10,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	210.00
TWO CONDUITS OPERATING	

EFFECT OF WEDGE-SHAPED FILLET AT CONDUIT EXIT PORTALS ON VELOCITIES AT END SILL



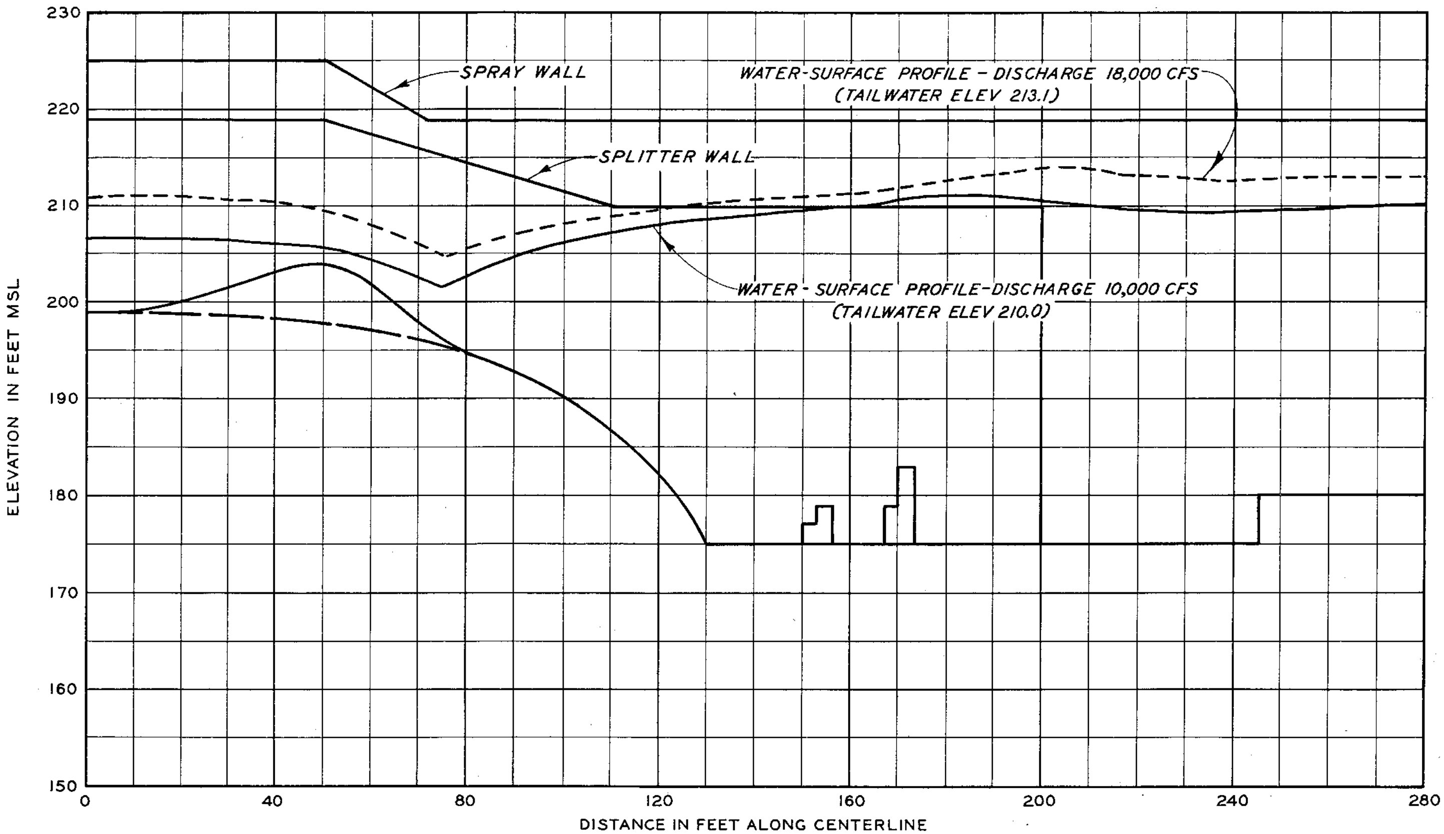
STILLING BASIN

RECOMMENDED DESIGN

SCALES

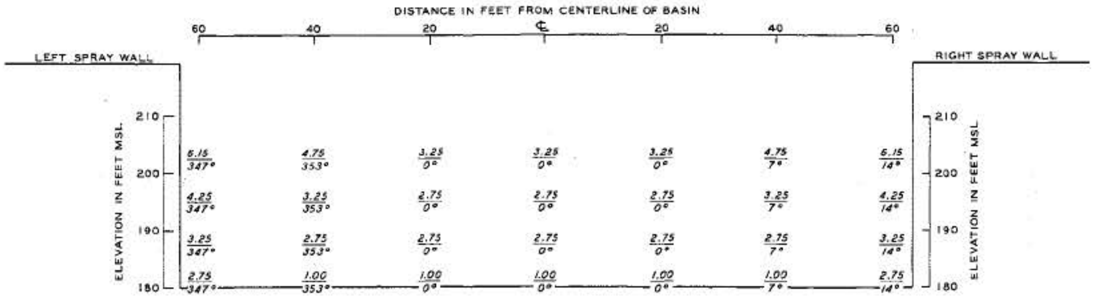
PROTOTYPE 25 0 25 50 75 100 FT

MODEL 1 0 1 2 3 4 FT



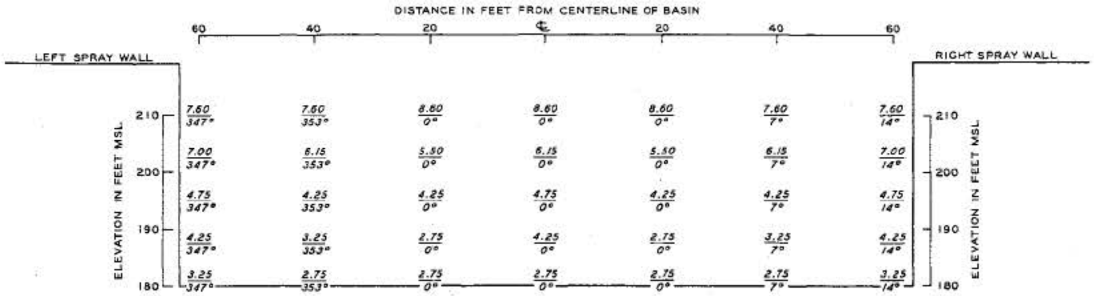
NOTE: POOL ELEVATION = 259.5

WATER - SURFACE PROFILE
RECOMMENDED DESIGN



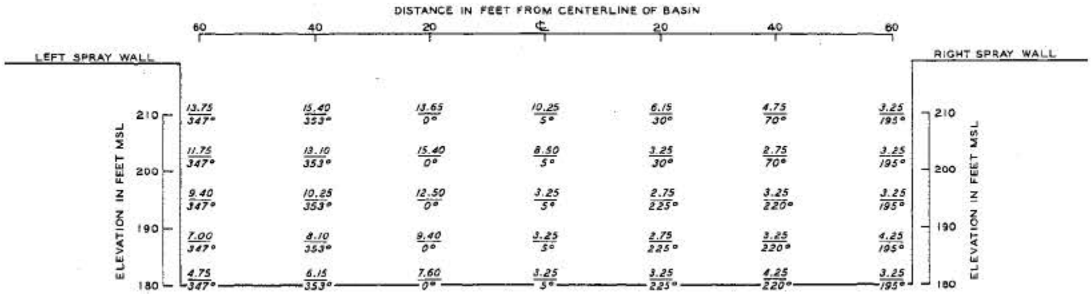
TEST CONDITIONS

DISCHARGE	5,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	203.95
TWO CONDUITS OPERATING	



TEST CONDITIONS

DISCHARGE	10,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	210.00
TWO CONDUITS OPERATING	



TEST CONDITIONS

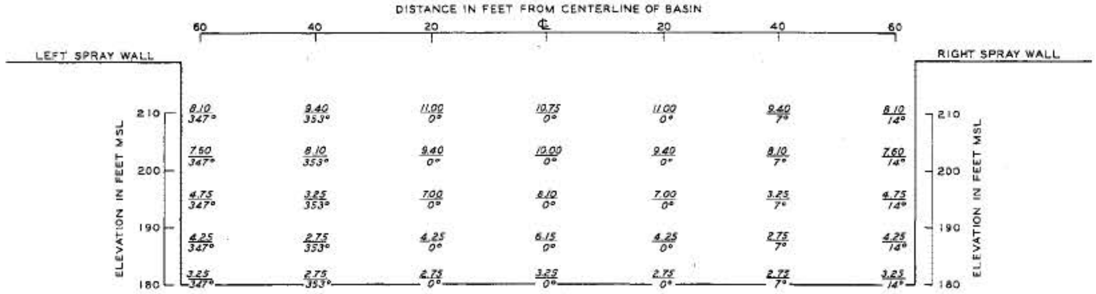
DISCHARGE	14,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	212.30
ONE CONDUIT OPERATING	

NOTE: FIGURE ABOVE LINE IS VELOCITY IN PROTOTYPE FEET PER SECOND.
FIGURE BELOW LINE INDICATES ANGLE OF FLOW MEASURED CLOCKWISE FROM DOWNSTREAM DIRECTION.

VELOCITIES AT END SILL

RECOMMENDED DESIGN

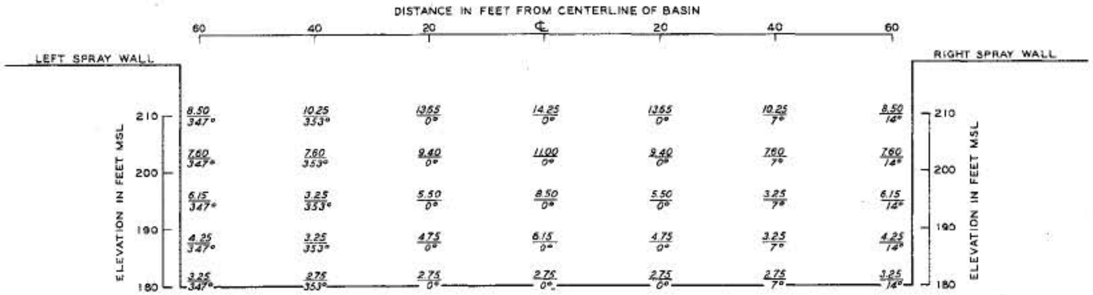
5,000 CFS, 10,000 CFS AND 14,000 CFS



TEST CONDITIONS

DISCHARGE	15,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	212.45

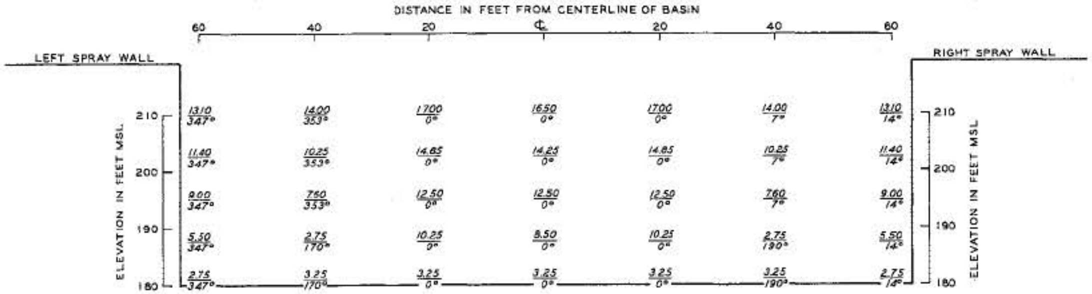
TWO CONDUITS OPERATING



TEST CONDITIONS

DISCHARGE	18,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	213.10

TWO CONDUITS OPERATING



TEST CONDITIONS

DISCHARGE	28,000 CFS
POOL ELEVATION	259.50
TAILWATER ELEVATION	214.70

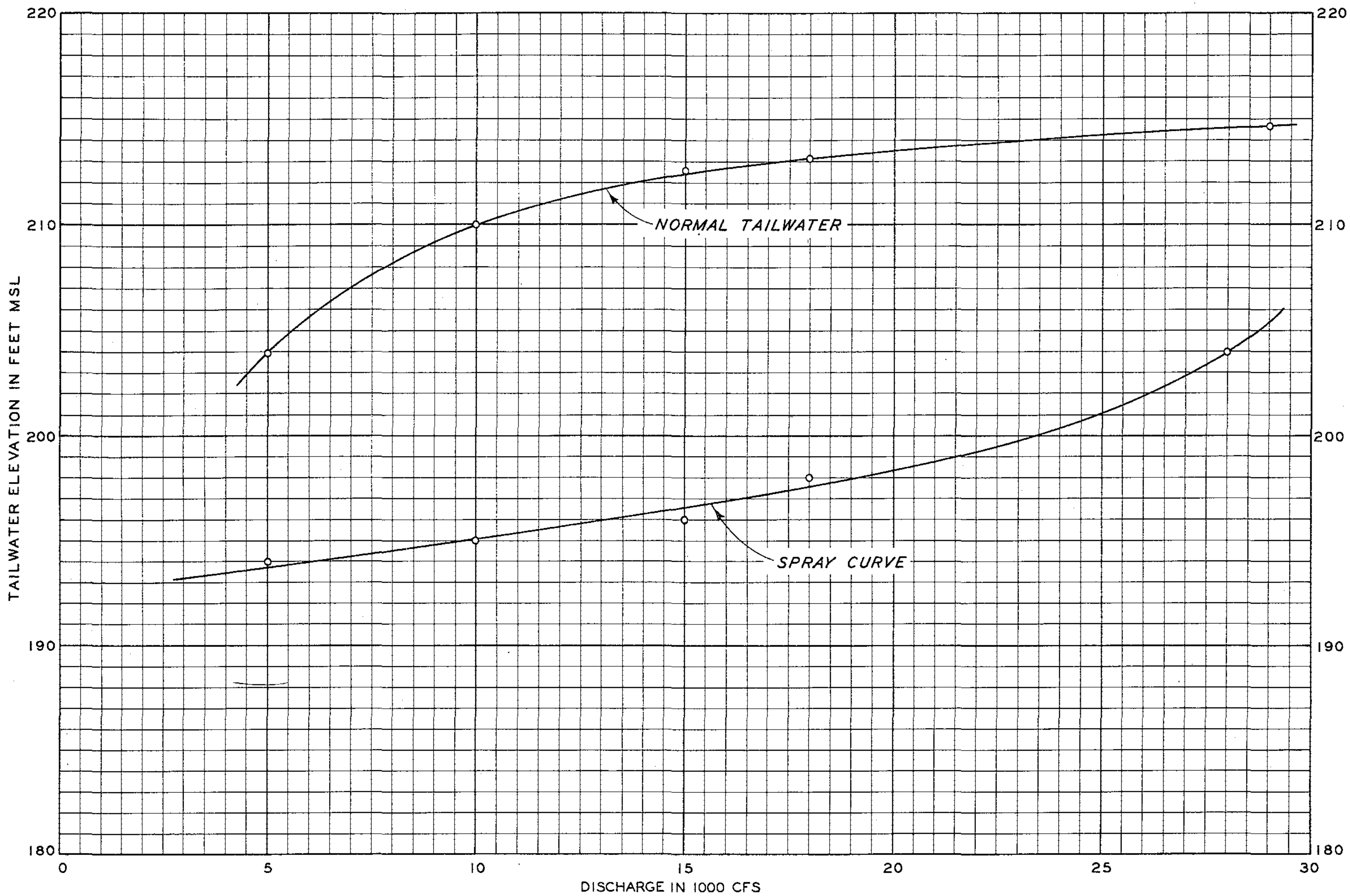
TWO CONDUITS OPERATING

NOTE: FIGURE ABOVE LINE IS VELOCITY IN PROTOTYPE FEET PER SECOND.
FIGURE BELOW LINE INDICATES ANGLE OF FLOW MEASURED CLOCKWISE FROM DOWNSTREAM DIRECTION.

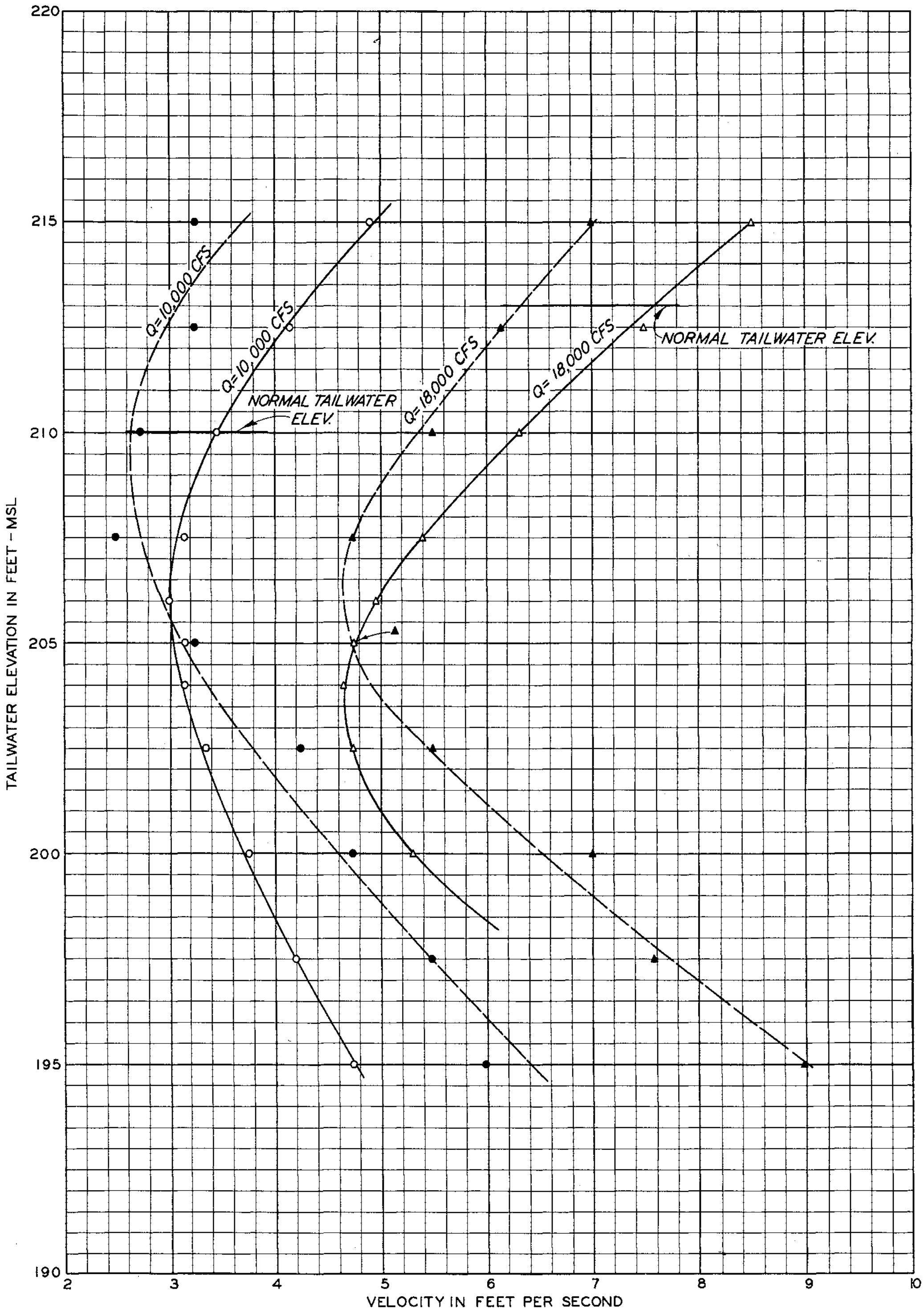
VELOCITIES AT END SILL

RECOMMENDED DESIGN

15,000 CFS, 18,000 CFS AND 28,000 CFS



TAILWATER CURVES



LEGEND

——— ORIGINAL DESIGN
— — — RECOMMENDED DESIGN

NOTE: VELOCITIES MEASURED ONE FOOT ABOVE END SILL.

TAILWATER VS VELOCITY CURVES